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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Structure of Metals

INSTN. METALLURGISTS: 'The Structure of Metals: A Modern Conception.'

Published, for the Institution, by *Iliffe and Sons, Ltd.*, London; *Interscience Publishers, Inc.*, New York, 1959; 118 pp. Price 25/-.

Each year since 1947 The Institution of Metallurgists has held a Refresher Course for its members, during which four leading authorities have surveyed the current state of knowledge in relation to a particular field of metallurgy. Originally the papers presented were re-published in book form solely for the benefit of members, but in view of the value of the information in these volumes it was decided that, as from 1956, papers presented at the Refresher Courses should be made available to the general public. The papers contained in the first volume published under this arrangement, given at a Course on 'Behaviour of Metals at Elevated Temperatures', were abstracted in *Nickel Bulletin*, 1957, vol. 30, No. 11, pp. 205-6.

The four lectures comprising the present book were delivered at the Course held in 1958. The introductory paper by G. V. RAYNOR, which is concerned with developments, over the past twenty or thirty years, in the electron theory of metals, summarizes modern concepts of the subject. In the next paper J. A. CATTERALL describes the experimental techniques evolved to investigate the nature of the valence band, and compares the results obtained with the theoretical models. A. G. QUARRELL discusses the dislocation theory of plastic deformation, and in the final paper J. NUTTING demonstrates that this theory has now been justified by experiment. Experimental techniques are outlined.

Thermal Conductivity of Aircraft Materials

I. B. FIELDHOUSE: 'Thermal Conductivity of Aircraft Structural and Reactor Materials.'

Amer. Soc. Mechanical Engineers, Symposium on Thermodynamics and Transport Properties of Gases, Liquids and Solids, pp. 391-9.

Report published by *McGraw-Hill Publishing Co. Ltd.*, London, 1959. Price 97/-.

Report of determinations of the thermal conductivity of eleven materials which may have application in aircraft structures or in reactors. Two methods were used: (1) a single-plate technique, and (2) the radial heat-flow method developed by Powell. The essential features of each procedure are described, with illustrations of the apparatus. The materials studied are shown below:

'Hastelloy B'	Determined by method (1)
'Hastelloy C'	
'Stellite 21'	
Chromium Steel, Type 446	
Silicon Carbide	
Austenitic Chromium-Nickel Steel containing molybdenum	Determined by method (2)
Austenitic Chromium-Nickel Steel stabilized with niobium	
'Hastelloy R-235'	
Aluminium Oxide	
Niobium	
Lithium Hydride	

Preliminary tests were made by method (2) on Armco iron, to confirm the accuracy of the apparatus.

Specific Heat of Materials

See abstract on p. 231.

Apparatus for Determination of Corrosion Rates under Heat-Flux Conditions

See abstract on p. 230.

NICKEL

Extraction of Nickel from Sudbury Ores

MOND NICKEL CO. LTD.: 'Flow Chart illustrating the Operations of the International Nickel Company of Canada, Ltd.'

Publn. 1649*, 1959; 12 pp. letterfold.

Four-colour flowsheet chart illustrating the operations involved in the extraction of nickel and thirteen other elements from the ores mined at Sudbury by the International Nickel Company of Canada, Ltd. The chart is one of the educational aids issued by The Mond Nickel Company, Ltd., primarily for the use of students of metallurgy and chemistry at the technical colleges and universities.

* *We shall be pleased to supply a free copy of this publication.*

Production of Nickel Strip by the Direct-Rolling Process

D. K. WORN: 'Production of Pure Nickel Strip by the Direct-Rolling Process.'

Powder Metallurgy, 1959, No. 3, pp. 45–71.

The investigation described was carried out to determine the feasibility of applying the direct-rolling technique to the production, from carbonyl-nickel powder, of pure nickel strip (6-in. wide and 0·03-in. thick: 15-cm. wide and 0·075-mm. thick) equal in quality to that produced by conventional processes. The main emphasis of the study was on determination of the influence of compacting-mill variables, on the properties and rate of output of *green* strip.

For the major portion of the work a 50:50 mixture of 'grade A' and 'grade B' carbonyl nickel was employed as raw material, though, with the object of assessing the relationship between the properties of the strip and the characteristics of the nickel powder, some experiments were made also with experimental grades. The compacting rolls were $7\frac{5}{8}$ in. (19 cm.) in diameter and were arranged in a horizontal plane. The general layout of the compacting rolls and sintering furnace is described.

The test programme involved three phases:

(1) Determination of the influence, on the properties of the green strip, of variation in roll gap, rolling speed, the head of powder above the roll gap, and the raw materials used.

(2) Study of the variables associated with sintering and processing the strip.

(3) Determination of the properties of the fully processed strip.

Increase in roll-gap setting resulted in an increase in thickness of the strip and a rapid decrease in density and breaking strength. For a given powder head and roll-gap setting, there was progressive reduction in the thickness, density and breaking strength of the green strip as the speed of rolling was increased, associated with a reduction in roll pressure. Irrespective of roll-gap settings and rolling speeds, the thickness, breaking strength and density of the green strip were found to increase with increasing powder head, but these increases became progressively less marked when higher rolling speeds were used. Results of tests with experimental grades of powder having bulk densities intermediate between those of grades 'A' and 'B' were consistent with the particle characteristics of the powders. Optimum properties were obtained by using a 'B' type powder of irregular fibrous particle form: relatively inferior ductility was exhibited by strip produced from high-bulk-density powders having more rounded and more discrete particles. The findings of these experiments are in general agreement with results of earlier work, from which it was concluded that for a given pair of compacting rolls the maximum thickness of strip that can be produced from a given raw material is severely limited.

It was apparent during the investigation that, owing to the interference of powder flow to the roll gap by the escape of entrapped air, it is impossible, above a certain rolling speed, to attain, by simple powder-feed devices, the limiting thickness of strip at which splitting occurs. This problem was partially overcome by the substitution of hydrogen or other low-viscosity gas for the entrapped air. This modification has raised the output potential of the process to a level considered satisfactory for commercial use: even with the small experimental mill used in the work described an output of over 200 lb./hour (90 kg./hour) was achieved.

Sintering and processing of green strip of adequate strength presented no insurmountable difficulties, and it is considered that these operations can be effected on conventional production plant, using (with minor modifications) normal processing schedules. Typical data for fully processed strip show that the quality of the product compares favourably with that of conventionally produced material and the purity of the powder product is considerably higher than that achieved by normal melting methods.

Creep of Nickel

E. A. MINKINA, N. V. PREOBRAZHENSKAYA and V. M. ROZENBERG: 'A Study of Deformation of Nickel in Creep.'

Isvest. Akad. Nauk S.S.S.R., Otdel. Tekhn. Nauk (Metall. Topl.), 1959, Mar.–Apr., pp. 48–55.

The studies reported were made on 99·95 per cent. pure nickel, over the temperature range 400°–800°C.

Magnetic Properties of Nickel

See abstract on p. 216.

Influence of Nickel on Beer

J. M. M. LUYKX and H. VAN VELDHUIZEN: 'The Part Played by Nickel in Foam Stability of Beer.'

International Tijdschrift voor Brouwerij en Mouterij, 1958, vol. 18, pp. 19–28.

Chemical Abstracts, 1959, vol. 53, p. 4647.

Additions of 1, 3 and 5 p.p.m. of bivalent nickel ion to a 12 per cent. pasteurized bottled beer of the Pilsener type was found to increase the foam stability by, respectively, 18, 43 and 63 per cent. No deleterious effects on clarity, cold haze or taste could be detected.

Influence of Variables in Preparation of Nickel Oxide on Sintering Properties

Y. IIDA and S. OZAKI: 'Sintering of High-Purity Nickel Oxide, II.'

Jnl. Amer. Ceramic Soc., 1959, vol. 42, May 1, pp. 219–28.

It is known that the chemical and physical properties of metal oxides vary according to the method of preparation of the oxides. These effects were studied by the authors, in an earlier investigation, on oxides

prepared by ignition of nickel nitrate (*ibid.*, 1958, vol. 41, pp. 397–406). The second report describes a parallel study on the sintering qualities of oxides prepared from nickel sulphate, oxalate, hydroxide, carbonate and nitrate, all having essentially the same degree of purity. The influence of the following variables was studied: particle size of the oxide, compacting pressure, additives, and mode of preparation of the oxide. The experiments are reported in detail and the paper is well illustrated by photomicrographs showing the form of the oxides prepared by the respective methods and the structures developed by various combinations of sintering conditions.

The conclusions are briefly summarized as follows: 'A low calcining temperature results in a high bulk density of a sintered compact. No appreciable change in the rate of sintering is found above 1000 kg./cm.^{2}, whereas the unheated density increases with increasing pressures. Additions of CaO promote sintering; additions of Na_2O, Fe_2O_3 and Al_2O_3 retard sintering; CeO_2 and Ag_2O have no effect; B_2O_3 accelerates grain growth but retards densification. Nickel oxide prepared from the oxalate has a small rate of sintering, as compared with nickel oxides from hydroxide, nitrate, and carbonate.'

Determination of Nickel in Cobalt and its Salts

W. NIELSCH: 'Photometric Determination of Nickel in Cobalt and its Salts, using Sodium Diemethylglyoxime.'

Zeitsch. f. Metallkunde, 1959, vol. 50, Apr., pp. 234–6.

The neutral test solution is treated with sufficient potassium cyanide to form a complex. The potassium cobaltocyanide is oxidized with hydrogen peroxide to potassium cobalticyanide, and the nickel is then extracted by addition of formaldehyde and sodium dimethylglyoxime. Finally chloroform is added, the solution is shaken, and the nickel dimethylglyoxime is photometrically measured (at 366 mμ) against a blank solution subjected to similar treatment. The technique provides, with minor variations in procedure, for determination of nickel in amounts ranging from 0·001 to 0·5 per cent.

Spectrophotometric Determination of Cobalt, Nickel and Copper

W. D. JACOBS and J. H. YOE: 'Simultaneous Spectrophotometric Determination of Traces of Cobalt, Nickel and Copper with Dithio-Oxamide.'

Analytica Chimica Acta, 1959, vol. 20, Apr., pp. 332–9.

The authors describe the cobalt, nickel and copper complexes of dithio-oxamide in terms of colour, effective pH, structure *in solution*, order of addition of reagents, adherence to Beer's law, and sensitivity. The reactivity of the reagent to other ions is also considered.

The analytical method described is based on the reactions of cobalt, nickel and copper with dithio-oxamide (rubeanic acid). Full working details are given and the validity of the procedure is demonstrated by results obtained on synthetic samples and on N.B.S. standardized samples of aluminium alloys and ferro-silicon.

Pickling and Acid-Dipping Solutions for Nickel

See abstract on p. 216.

Nickel in Butane-Isomerization Units

See abstract on p. 237.

ELECTRODEPOSITION AND OTHER COATING METHODS

Fundamental Research in Nickel Plating

B. E. CONWAY and J. O'M. BOCKRIS: 'An Introduction to Fundamental Research on the Mechanism of the Electrodeposition of Metals.'

Plating, 1959, vol. 46, Apr., pp. 371–83.

This paper 'represents an attempt to describe to the electroplater who understands the basic ideas of electrochemistry what is being done in research on fundamental electrode processes and, in particular, how electrochemical workers are tackling the problem of finding out the sequence and nature of the ionic and molecular events which occur during electroplating'.

Problems which have been the object of research of a fundamental character are described, together with some typical experimental techniques which have been used in such research. An informal definition is given of some of the terminology and fundamental ideas which are used by electrochemists in discussing the mechanism of electrodeposition. Finally, a summary is made of the way in which evidence concerning the rate-determining step in a typical simple metal deposition reaction has been obtained in research carried out at the University of Pennsylvania and the University of Ottawa, under the aegis of A.E.S. Research Project No. 16.

The significance of such work to the practical plater is emphasized. It is pointed out that the basic mechanisms of electrodeposition are not generally understood, since the theory of electrode kinetics has only recently been seriously investigated. The article constitutes an attempt to bridge the wide gap between practice and theory in the electroplating industry.

Electrodeposition of Metals on Thorium

J. G. BEACH and G. R. SCHAER: 'Electroplating on Thorium.'

Jnl. Electrochemical Soc., 1959, vol. 106, May, pp. 392–3.

The main part of the paper, dealing with development of a method of plating thorium with aluminium, chromium, copper, iron, nickel, gold, indium, silver, zinc, lead and tin, is based on information

which was presented in detail by the authors, in collaboration with FAUST, in *U.S. Atomic Energy Commission Report BMI-T-7* (see abstract in *Nickel Bulletin*, 1958, vol. 31, No. 6, p. 164). The present paper, however, contains also short notes on an investigation of the resistance to corrosion in hot water conferred on thorium by various electroplated or conversion coatings. Copper, iron, nickel and silver offer promise in this connexion, though further study needs to be made of the interdiffusion of thorium and these metals, and of the alloys so formed. Anodizing of the thorium, followed by heat-treatment, produces a protective thorium-phosphate film which favours resistance to corrosion by hot water.

Influence of Magnesium-Salt Additions in Nickel-Plating Solutions

A. GENEIDY, W. A. KOEHLER and W. MACHU: 'The Effect of Magnesium Salts on Nickel-Plating Baths.' *Jnl. Electrochemical Soc.*, 1959, vol. 106, May, pp. 394–403.

Magnesium sulphate is among the salts which may be added to improve the conductivity of nickel-plating electrolytes, but consideration of the literature relating to the use of this additive (the present paper is supported by a *bibliography* of 106 items) demonstrates a strong conflict of opinion as to the beneficial or harmful effects resulting from its use. Since it appeared that no systematic study had previously been made of the influence of such additions, on the operation of the nickel-plating solution and the properties of the electrodeposit, the investigation described by the authors was planned to obtain quantitative data in this respect.

The nickel-plating solutions selected for study were of the Watts sulphate or Wesley all-chloride types. Since anions influence the character of the deposit, additions of magnesium sulphate were made to the former solutions and magnesium chloride was used for the latter. To permit comparison of the effects of magnesium ions in the two solutions, the salts were added (in concentrations representative of normal plating practice) in equinormal amounts rather than in equal percentages.

To assess the influence of the magnesium-salt additions on the operation of the solution, measurements were made of cathode and decomposition potentials, cathode current efficiency, and throwing power. The properties of the deposits produced from the solutions were determined by tensile and hardness tests on electroformed nickel sheets, by structural studies (using X-ray-diffraction techniques), and by porosity tests. The deposits were also subjected to spectrographic analysis, to determine whether magnesium was co-deposited with the nickel.

Full details are given of plating conditions, test techniques, and the results obtained. The authors summarize their conclusions as follows:

'As a result of the present investigation, it is concluded that addition of high concentrations of magnesium to nickel baths makes the deposition potential of nickel more noble, reduces cathode polarization, does not change the face-centred-cubic lattice of nickel, co-deposits only spectroscopic traces of magnesium, increases cathode current efficiency slightly, improves the throwing power, reduces porosity, and makes nickel deposits harder, stronger, and less ductile.

'In the plating industry, use can be made of the effect of magnesium additions to nickel baths. It is shown that by addition of 2*N* magnesium sulphate to the Watts bath, a bath can be obtained the properties of which lie nearly midway between those of Watts and Wesley baths. The same effect can be brought about by increasing the chloride content of the Watts bath, but addition of magnesium sulphate has certain advantages:

'(1) Magnesium sulphate is less expensive than nickel chloride.

'(2) The corrosive nature of the Watts bath will not be increased, whereas it will be much increased if the nickel-chloride content is increased.

'(3) In the presence of magnesium salts, nickel baths hold their metallic concentration better than they do without magnesium salts; addition of acid to correct the pH is less often needed.

'(4) Addition of magnesium sulphate will improve the corrosion-resistance of the deposit, whereas increasing the nickel-chloride content will not improve that property. An evidence of this is the fact that the Wesley bath, which is made solely of nickel chloride, gives deposits having corrosion-resistance identical to that of deposits obtained from the Watts bath. This result was found by Wesley and Carey (*Trans. Electrochemical Soc.*, 1939, vol. 75, p. 209), and was confirmed in the work now reported.'

It is suggested that further research is desirable, to determine whether addition of still higher concentrations of magnesium sulphate to Watts baths will result in deposits having mechanical properties closer to those obtained from the Wesley all-chloride solution, without the disadvantage of the higher tensile stresses characteristic of those deposits.

Influence of Metal-Salt Additions in Electroless Nickel-Plating Solutions

W. MACHU and S. EL-GENDI: 'Influence of Heavy-Metal Salts on the Brightness and Rate of Deposition of Nickel Deposited from Electroless-Plating Solutions. The Reaction Mechanism of Electroless Deposition of Nickel.'

Metalloberfläche, 1959, vol. 13, Apr., pp. 97–103.

Although the use of brightening additions in electrodeposition of nickel has been the subject of much study and is now relatively well established, little work has been carried out to determine the feasibility of using similar addition agents to obtain bright nickel deposits from electroless-plating solutions. The research reported in this paper was confined to investigation of the effect of inorganic

metal salts which had already proved their value as brightening agents in electroplating: cobalt acetate, zinc sulphate, cadmium sulphate and uranium acetate. The aim of the experiments was threefold:

(1) to determine the effects of such additions on the brightness and rate of deposition of nickel deposited from a solution of the sodium-hypophosphite type;

(2) to study the catalytic effects of such additions;

(3) to throw light on the mechanism of nickel deposition and the causes of brightening.

The plating solution, which was operated at a pH of 9·15 and a temperature of 82° or 92°C., was of the following composition:

	g./L.
$NiCl_2.6H_2O$	30
$NaH_2PO_2.H_2O$	10
Sodium citrate	97·5
NH_4Cl	47·5

Aluminium plates were used as cathodes. The salts were added in amounts which, depending on the particular additive, ranged from 0 to 30 g./L. The phosphorus content of the deposits obtained was in the region of 7·4 per cent. Brightness was assessed in percentages of the reflectivity of a silver mirror, and is presented, together with data on the weight and thickness of the nickel coating, as a function of concentration of brightening agent.

With a cobalt-acetate addition, brightness of the coatings and rate of deposition both increased approximately linearly with increase in salt content until, at a certain concentration, the deposits began to splinter. With increasing additions of zinc sulphate, however, brightness and weight increased to a maximum and then decreased. The general effects of cadmium-sulphate additions were similar to those of the zinc sulphate, but it was found that nickel could be deposited only in the presence of small concentrations of this brightening agent: at higher concentrations the aluminium cathode was anodically polarized by contact with the sludge-like co-deposited cadmium and was thereby corroded. The effects of increasing amounts of uranium acetate were reflected in a steady reduction in the weight of nickel deposited and by an improvement in brightness, values for which reached a maximum and then fell away.

The addition agents studied were found to exhibit the characteristics of inhibitors, and it is to their inhibitory effects that increase in brightness and decrease in the weight of the deposits are attributed.

The authors advance a new theory which seeks to explain the deposition of nickel and phosphorus in terms of electrochemistry.

Quality of Nickel/Chromium Plating

Further to commentaries on the quality of the nickel/chromium plating of twenty years ago and that of later years (see, for example, abstracts in *Nickel Bulletin*, 1959, vol. 32, Nos. 4 and 6, pp. 146 and 197), other contributions have been made, both in the U.K. and the U.S.A., to discussion of this subject. All who give balanced consideration to the numerous factors influencing the behaviour of plating under modern conditions come to broadly similar conclusions; for example, one writer sums up the position by saying 'The important thing seems to be that the chromium plate of to-day isn't really inferior. We are just demanding more of it. No one will dispute that there is room for improvement, but, after all the effort which has been expended to upgrade the quality, it really is quite unreasonable to maintain that the finish is actually worse.'

Attention is repeatedly called to the complications which have been introduced by contamination of the atmosphere, which is much greater at the present time than in the 1930's, to the more severe service to which cars, for example, are subjected, and to the lack of time and care expended on maintenance of plated parts, all of which factors tend to accelerate deterioration. A further quotation aptly summarizes the position:

'All this does not amount to saying that nickel/chromium plating to-day is all that it should be, and that it measures up to the demands made upon it in service on a modern motor car. That there is considerable scope for improvement few would dispute, but this is a very different matter from coming to the conclusion that the quality of modern plating is inferior to that which was obtainable in the past. If this were indeed the case, the situation would be depressing, for it would mean that all the efforts of the last decade to improve processes and control methods and to mechanize production, together with all the research that has gone into the causes of corrosion and its prevention by electrodeposition, have led to a standard of finish which is markedly inferior to that which was produced years ago by relatively crude and unscientific rule-of-thumb methods. Such a conclusion is clearly unacceptable.'

In the above connexion *see*

R. SILMAN: 'Has Chromium Plating Deteriorated ?' *Product Finishing*, 1959, vol. 12, Feb., pp. 65–72.

N. HALL: 'Is it Really as Bad as They Say ?' *Metal Finishing*, 1959, vol. 57, May, p. 47.

Thickness of Nickel Electrodeposits: Proposed Amendments to A.S.T.M. Specification

'Electrodeposited Metallic Coatings.' *A.S.T.M. Bull.*, 1959, Apr., p. 41.

The note quoted on p. 214 forms part of a report summarizing the recommendations which will be presented by the various technical committees at the 1959 Annual Meeting of the American Society for Testing Materials. It is of interest in the light of recent trends towards increasing the thickness of nickel electrodeposits to secure improved corrosion-resistance.

'*Electrodeposited Metallic Coatings Committee* (B-8).

'Action was taken to double the specified nickel-plate thickness in Specification B.142, covering electrodeposited coatings of nickel and chromium on zinc and zinc-base alloys. To improve the durability and performance of plated zinc die-castings, the new coating, designated Type DZ, would have the following minimum thickness requirements: copper+nickel, 0·002 in.; copper, 0·0002 in.; final nickel, 0·001 in.; and chromium, if required, 0·00001 in.

'A proposed specification for electrodeposited coatings of nickel on steel for engineering use is being developed. This specification covers requirements where protection against corrosion, wear, abrasion, erosion, oxidation, or other deterioration of the basis metal is important, as well as product protection from iron contamination in vessels used for storage and handling of such materials. The type of nickel coating used will depend upon the requirements of the articles to be coated. Selection must be based on the experience of the manufacturer and the purchaser with regard to the thickness, hardness, ductility, residual stress, and other properties of the nickel coating.'

Electrodeposited Coatings: Measurement of Thickness

COMMITTEE FOR STANDARDS, MEASURES AND MEASURING INSTRUMENTS, COUNCIL OF MINISTERS OF U.S.S.R: 'Electrolytic Protective and Decorative Coatings: Methods of Measuring the Thickness of Zinc, Cadmium, Copper, Nickel and Multiple Deposits.' *Gost* 3003-58; 27 pp. Published 1959.

The Standard covers in detail instruments, chemicals and techniques to be used in the measurement of thickness of nickel, nickel-copper, cadmium, copper, zinc and multiple electrolytic deposits, using chemical and/or physical methods. The procedures include jet tests, drop methods, removal of deposit, weighing before and after deposition, and magnetic and radioactive procedures.

The Brenner and Senderoff Contractometer

H. FRY and F. G. MORRIS: 'Construction and Use of the Brenner and Senderoff Contractometer for the Measurement of Stress in Electrodeposits.' *Electroplating and Metal Finishing*, 1959, vol. 12, June, pp. 207–14.

The fundamental importance of internal stress as a factor affecting the quality and service performance of electrodeposited coatings and electroformed parts is now fully recognized. Spontaneous cracking of decorative coatings may occur if stress becomes too high in relation to ductility; fall in fatigue limit of plated materials is related to the internal stress present in the coating, and, in the case of electroformed components, high stress can lead to distortion. Much interest has therefore been shown in development of methods for measurement of stress, and this has been stimulated by the fact that such measurements can play an important part in elucidating other properties of electrodeposits. For example, studies of the effect, on stress, of organic additions to nickel-plating solutions give some information on the way in which the addition agents are incorporated in the deposit; other investigations have shown that stress in chromium deposits is related to their structure, and stress measurement has been used also to determine the thickness at which chromium deposits crack during deposition.

Many experimental techniques have been proposed for measurement of stress, but few of them are suitable for use in routine plating control. In 1949, however, BRENNER and SENDEROFF proposed a method which showed promise of large-scale applicability (see *Jnl. Research, Nat. Bur. Standards*, vol. 42, p. 89), and it is with the evaluation of that technique that the present paper is concerned. The report covers an investigation carried out in the laboratories of the British Non-Ferrous Metals Research Association, in the course of which the accuracy and reproducibility of the original model was tested and modifications were made to enhance its practical usefulness.

The contractometer takes advantage of the fact that, when a thin sheet is plated on one surface only, the stresses present in the deposit cause the strip to bend. In using the apparatus, the strip is wound into a helix, with one end fixed and the other free to rotate. When the strip is plated the motion of the free end is communicated to a pointer by a system of gears.

The contractometer as initially built by the authors, from constructional details given by the inventors, did not yield reproducible results, but modifications which reduced friction and backlash corrected this irregularity, and it is considered that in the modified form the instrument is suitable not only for research work, but also for day-to-day supervision of electroplating solutions by a skilled assistant.

The paper contains detailed drawings of each component of the contractometer and instructions for construction of the instrument, and preparation, calibration and plating of the helices. The electrolysis vessel and anode are described and particulars are given of the method of taking readings, and of calculating mean and instantaneous stress. A note is included on the accuracy and reproducibility of the results obtained.

(The information presented was issued to members of the B.N.F.M.R.A. in a confidential Research Report in September 1958.)

Hydrogen Content of Nickel, Nickel-Zinc and Nickel-Thallium Electrodeposits

E. RAUB and F. SAUTTER: 'The Hydrogen Content of Electrodeposited Nickel.' *Metalloberfläche*, 1959, vol. 13, May, pp. 129–32.

The investigation reported comprised a systematic attempt to establish the degree to which hydrogen pick-up is influenced by composition of the solution, pH, current density, agitation, and temperature of the electrolyte.

Three types of plating solution were selected for study: chloride, sulphate, and sulphate/chloride. The influence of pH was determined over the range 1-5·8 or 6·5; the effects of temperature were studied at 20°, 50° and 90°C., and cathodic current density was varied within the range 0·5 to 3 amp./dm.^{2}. The effects, on the hydrogen content of electrodeposited nickel, of the presence of alloying elements were established by analysis of solid-solution alloys produced by co-deposition of nickel and zinc and nickel and thallium. The deposits were removed from the cathode base, and determination of their hydrogen contents was effected by a technique involving extraction *in vacuo* at 400°C.

The amount of hydrogen present in the deposits was found to vary greatly. Supersaturation of the nickel with hydrogen was to a great extent independent of the amount of hydrogen discharged; the results demonstrated, however, that hydrogen pick-up was considerably influenced by solution composition, pH value and temperature.

Examination of the electrodeposited nickel-rich zinc and thallium alloys showed that hydrogen contents could be very high, depending upon the amount of alloying metal co-deposited. The degree to which the nickel was supersaturated with hydrogen was governed by the state of the lattice: a large degree of distortion gave rise to a high pick-up. Lattice distortion is not the result, but the cause, of high susceptibility to hydrogen pick-up and can be attributed to presence of other contaminating materials introduced during crystallisation of the nickel.

Nickel Undercoat in Gold Plating of Molybdenum

R. W. ETTER: 'Cathodic Electrocleaning of Molybdenum Wire prior to Gold Plating.'

Symposium on Cleaning of Electronic-Device Components and Materials.

Published by *Amer. Soc. Testing Materials*, as *Special Tech. Publn. No.* 246, 1959, pp. 129-33; disc. pp. 133-5.

Molybdenum wire used for grids of electron tubes must, in many cases, be plated with gold, to minimize secondary emission. The objects of the investigation outlined in the paper were three-fold: (1) to determine the types of contaminant which may be present on molybdenum wire, adversely influencing adherence of the gold deposit; (2) to establish optimum procedures for cleaning hot-drawn molybdenum wire; (3) to investigate the suitability of nickel plating as an undercoating for gold deposits.

Contamination of the wire was found to be due mainly to surface oxidation during fabrication. Attempts to develop an effective cleaning technique resulted in selection of cathodic treatment in sulphuric-acid solution (65-75 vol. concentration) at room temperature, for about 20 seconds.

The problem of providing a surface suitable for subsequent electrodeposition of the gold coating was approached from the point of view of the intersolubility of molybdenum and the proposed undercoating metal and of the undercoating metal with gold. Molybdenum is not soluble in gold even at 1500°C., but nickel is soluble both in gold and in molybdenum. It therefore appeared likely that adherence of the gold deposit would be improved by electrodeposition of an undercoating of nickel, coating with gold, and finally firing the composite coating in an atmosphere of dry hydrogen at a temperature in the range 950°-1050°C. Excellent adhesion was obtained by this procedure, provided that two precautions were observed: (1) avoidance of blistering is contingent on firing the electrocleaned molybdenum wire in dry hydrogen for at least 5 minutes, at 900°-1050°C., prior to nickel plating; (2) the weight of the nickel undercoating in relation to that of the wire is critical: it should be in the range 0·1-0·4 wt. per cent. The electrolyte used is a conventional chloride type.

Engineering Applications of Nickel Plating

L. F. SPENCER: 'Engineering Uses of Plated Coatings.'

Metal Finishing, 1959, vol. 57, May, pp. 48-54.

The extensive use which is made of heavy nickel plating in the engineering industry may be attributed to (*a*) the relative ease with which such coatings may be deposited, even in areas which are difficult to coat by other procedures, (*b*) the range of mechanical properties available by selection of an appropriate plating solution, (*c*) the possibility of producing coatings as thick as 0·25 in. (0·6 cm.), which exhibit excellent bond strength, toughness and ductility and corrosion-resistance, (*d*) the ease with which the abrasion-resistance of the nickel can be increased by deposition of an overcoating of chromium.

Nickel plating finds its main engineering applications in the salvaging of worn or over-machined components and in the production of electroformed die components. In this article the author outlines the advantages of nickel plating in these applications, gives a general outline of the procedure used and, by way of illustrating the applicability of the two techniques, refers to components which have been successfully salvaged or electroformed.

The article, which is well illustrated, is introduced by a short review of the characteristics of commonly used plating solutions: it includes a section on the use of electrodeposited lead-tin alloys for bearing surfaces, and reference is made also to other metals which may be used in electroforming applications.

NON-FERROUS ALLOYS

Plastic Behaviour of Nickel-Cobalt Single Crystals

J. MEISSNER: 'Investigation of the Plasticity of Single Crystals of Nickel-Cobalt Alloys.'

Zeitsch. f. Metallkunde, 1959, vol. 50, Apr., pp. 207-17.

The plastic behaviour of single crystals of nickel and of nickel-cobalt alloys (produced by powder-metallurgy techniques and containing 10, 20, 30

or 40 per cent. of cobalt) was studied during tensile testing at room temperature and at 90°K. (−183°C.). From the data so obtained, shear-stress/shear-strain curves were derived: these are presented in the paper.

The curves show that the deformation behaviour of the alloys was characterized by three stages similar to those typical of the progress of deformation in face-centred-cubic metals: the flat, linear region associated with the first (easy-slip) stage; the considerably steeper, but still linear, region of the second stage; and the final region, represented by a gradual flattening out of the curve. The critical shear stress, the extent of the 'easy-slip' stage, and the stress at the beginning of the third stage were found to increase with fall in temperature and increase in cobalt content; the slope of the work-hardening curve in the second stage of linear hardening was, on the other hand, independent of temperature and composition. These findings were anticipated from extrapolation of the tensile properties of pure metals to materials of low stacking-fault energies. That the work-hardening parameters were influenced by variations in composition was the consequence of changes in stacking-fault energy, which decreases with increase in cobalt content.

'NIVCO': Cobalt-Nickel-base High-Damping Turbine-Blading Alloys

See abstract on p. 227.

Phases Present in Nickel-Copper-Germanium Alloys

W. BURKHARDT and K. SCHUBERT: 'Phase Structures of the Nickel-Copper-Germanium System.'
Zeitsch. f. Metallkunde, 1959, vol. 50, Apr., pp. 196–8.

But little information on the nickel-copper-germanium ternary system is available in the literature. This paper presents a section of the phase diagram which was determined by metallographic and X-ray examination of alloys isothermally annealed at 500°C. Of the phases studied, $Ni_3Cu_2Ge_2$ was of hexagonal structure, $Ni_{15}Cu_{65}Ge_{20}$ was of A13 type and at the $Ni_{15}Cu_{58}Ge_{22}$ composition phases akin to the γ-brass type were formed.

Ternary Carbides of Nickel with Germanium and Indium

L. J. HÜTTER and H. H. STADELMAIER: 'Ternary Carbides of the Transition Metals Nickel, Cobalt, Iron and Manganese with Germanium and Indium.'
Zeitsch. f. Metallkunde, 1959, vol. 50, Apr., pp. 199–203.

The transition metals nickel, cobalt, iron and manganese combine with a series of B metals to form ternary carbides of composition T_3BC_x (where T is the transition metal, B is the B metal and C is carbon). Such carbides, which have been variously reported in the literature, are characterized by a f.c.c. lattice in which the B-metal atoms are at the corners of the cube and the transition metals occupy the face centres. The present paper is concerned with the results of metallographic and X-ray examination of ternary carbides which the authors found were formed by the four transition metals named, and germanium and indium.

The production of the carbides is described and their electronic characteristics are discussed.

Magnetic Nickel-Iron Alloys

See abstract below.

Nickel Alloys in Butane-Isomerization Units

See abstract on p. 237.

Pickling and Acid-Dipping Solutions for Nickel-containing Materials

J. B. MOHLER: 'Pickling and Acid Dipping of Metals.'
Metal Finishing, 1959, vol. 57, May, pp. 63–7.

The article lists and discusses typical pickling and acid-dipping solutions variously used to treat, respectively, low-carbon steel, alloy steels, stainless steels, copper alloys, nickel and nickel alloys, zinc alloys, aluminium alloys and magnesium alloys. Acid treatments for cast iron and silver are also briefly considered.

The author emphasizes that the solutions listed are intended to serve only as a broad guide to aid in establishment of a specific process. They are 'generalisations taken from experience and authoritative sources'.

NICKEL-IRON ALLOYS

Magnetic Nickel-Iron Alloys

Papers presented at the *Conference on Magnetism and Magnetic Materials* held in Philadelphia in November 1958, under the auspices of the American Institute of Electrical Engineers, are published in a *Supplement* to the *Journal of Applied Physics*, April 1959. The range of subjects covered is indicated by the section classification of the material: papers of general interest, ferrites, computer components, micromagnetics and domain walls, magnetic properties of metals and alloys, fine particles, amplifiers and microwave applications, resonance, metallurgical considerations, fundamental interactions, instrumentation, thin films, neutron diffraction and irradiation, garnets and other compounds, anisotropy other than in thin films. Brief notes on matters of interest in some of the papers dealing with nickel-containing materials are given below.

(1) *Magnetic Properties of Metals and Alloys*

The contributions presented included papers relating to temperature-dependence of the magnetic properties of nickel-iron alloys, effects of composition and processing on the activity of magnetostrictive

materials (e.g., nickel, nickel-cobalt alloy, nickel-iron alloys and other materials), and the effects of exposure of 'Alnico' magnet alloys to elevated temperatures.

(2) *Metallurgical Factors of Significance in Relation to Magnetic Properties*

The papers include a report on observation of decomposition of austenite during room-temperature storage of 50-50 nickel-iron alloy tape, a study of a precipitation-hardening alloy of the 'Elinvar' type (in relation to its magnetic properties), and data on variation of orientation texture in molybdenum-'Permalloy' tape.

(3) *Fundamental Reactions in Magnetic Materials*

In this section are papers on hyperfine coupling in metals and alloys, electronic structure, magnetic contributions to the elastic constants of nickel and iron-nickel alloys, and various laws governing behaviour of ferromagnetic materials.

(4) *Thin Films*

This session contained papers dealing with the properties of films of magnetic nickel-iron alloys of various compositions. Aspects of the subject which are discussed by one or more of the authors include rotational hysteresis in thin films, slow domain wall motion, anisotropy, the Barkhausen effect, structural and magnetic properties, and the influence of substrate processing on properties.

(5) *Effect of Irradiation on Magnetic Materials*

The papers dealt with effects of irradiation on anisotropy and magnetostriction in nickel, nickel-iron alloys and other materials, and with the measurement of radiation effects.

Determination of Copper in Magnet Alloys

See abstract on p. 231.

CAST IRON

Thermal and Elastic Properties of Cast Irons used in Marine Diesel Engines

D. FITZGEORGE and J. A. POPE: 'The Thermal and Elastic Properties of Eight Cast Irons.'

Trans. North East Coast Instn. Engineers and Shipbuilders, 1959, vol. 75, Mar./Apr., pp. 285-330.

In *British Shipbuilding Research Association Report* No. 123 the authors presented the findings of an investigation of the factors contributing to the failure of diesel-engine pistons and cylinder covers. The major portion of the report was concerned with an analysis of the stress distribution obtaining in combustion-chamber parts under operational conditions. During the investigation particular attention was paid to the influence of design on the formation of stresses likely to cause failure, and, with a view to determining the possible effects of service temperatures, typical failures were subjected to metallographic examination. The results of the authors' analysis demonstrated the importance of the following factors:

(1) The tensile strength of the material and variation of strength (*a*) with temperature, and (*b*) with continued exposure at elevated temperatures.

(2) Resistance to rupture and the effects, in this connexion, of subjecting the material to small amounts of repeated plastic strain.

(3) Variation of Young's modulus with temperature.

(4) Variation of Young's modulus with total strain (studied on cast iron only).

(5) Variation of Poisson's ratio, and the coefficient of expansion, with temperature.

(6) Variation of thermal conductivity with temperature.

(7) Creep-resistance.

The investigation described in the present paper, comprising an extension of the earlier research, was carried out (on behalf of the British Shipbuilding Research Association) with the aim of evaluating, as a function of the seven factors listed above, the characteristics of eight grades of cast iron. The cast irons, selected for examination either as typical of those in actual use for combustion-chamber components or as being considered potentially suitable for that purpose, consisted of three plain flake-graphite types, three alloyed flake-graphite grades (nickel - molybdenum, copper - molybdenum and nickel-chromium), and two nickel-containing spheroidal-graphite types (one ferritic, the other pearlitic). Details of the composition, treatment and structure of each of the eight irons are given in the paper and the test programme is fully described. The data obtained are presented *in extenso* and discussed. The scope of the test programme is indicated below.

(1) *Determination of Tensile Strength and Bend Strength and Measurement of Hardness.*

(2) *Determination of Young's Modulus at Various Temperatures.*

(3) *Determination of Coefficients of Expansion.*

(4) *Determination of Density.*

(5) *Fatigue Tests at Temperatures in the range* 20°-550°C.

(6) *Determination of the Effects, on the Properties and Structure of the Irons, of Long-time Exposure at High Temperatures.*

(7) *Determination of the Thermal Conductivities of the Cast Irons over the range* 50°-500°C.

(8) *Determination of Eichelberg 'Quality Factors'**.

The data obtained lead to the conclusion that the

*For full details of these factors see *Forsch. Arbeit. Ing. Wesen*, 1923, No 263.

materials may be placed in the following descending order of suitability for use as combustion-chamber parts:

(*a*) Steel castings.

(*b*) Spheroidal-graphite cast iron with ferritic matrix.

(*c*) Spheroidal-graphite cast iron with pearlitic matrix.

(*d*) Flake-graphite cast iron with short thick flakes of graphite and low free-graphite content.

(*e*) Flake-graphite cast iron with long thin graphite flakes and high free-carbon content.

The modified form of Eichelberg quality factor used in the investigation proved to be of only limited value as a means of evaluating the cast irons.

Erosion by Cavitation Attack

See abstract on p. 231.

Use of 'Ni-Hard' for Grinding-Mill Liners

U. RUNOLINNA: 'Service Tests on Materials for Mill Liners.'

Zeitsch. f. Erzbergbau und Metallhüttenwesen, 1958, vol. 11, Sept., pp. 432-7.

Since the ore-processing plants at Otanmäki, Finland, came into operation in 1953 continuous attempts have been made to improve the life of the liners in the ball and rod mills used to grind the titanic iron ore to a fineness suitable for separation of the magnetite from the ilmenite. This paper gives details of service tests with various materials, and describes the design modifications entailed in the ultimate incorporation, into the mill liners, of martensitic nickel-chromium cast iron, which proved to be the most satisfactory material.

Originally the liners in both ball and rod mills consisted of bars of chromium-manganese steel, alternating with wooden bars used to minimize the weight of the lining. After initial experience with the ball mill had demonstrated the suitability of this set-up, further tests were made with a view to increasing the percentage of wooden bars from 20 to 40 a proportionate reduction in the metallic components of the lining was achieved by replacing the 80-mm.-wide steel bars with 30-mm.-wide bars in a nickel-chromium martensitic white cast iron (nickel 4·0–4·5, chromium 1·5–2·0, per cent.). The same material was to be used also for other parts of the liners. These tests showed the cast iron to be about nine times as wear-resistant as the steel: its use permitted changes in the design of the mill liners, which resulted in further savings in weight and material, and it is intended eventually to increase the proportion of wooden beams used to 50 per cent. and to make further use of the martensitic cast iron in the end liners. The cost of a lining of this type is expected to be only half that of a conventional lining and its use provides not only savings in initial costs but also the operational advantage of a much longer life (one wood/cast-iron lining is stated to be still in service after 60,000 hours' operation).

The use of wooden beams for part of the lining of the rod mill proved unsuccessful, since they split after a time, due to penetration of particles from the ore. Experiments to determine the feasibility of using nickel-chromium cast iron to replace the manganese and chromium-manganese steels at present employed for this application are in progress.

The paper includes data on the rates of wear of the various linings, and design modifications are illustrated by drawings.

See also following two abstracts.

H. G. DONOGHUE, W. S. ADAMS and C. E. HARPUR: 'Tilt Cove Copper Operation of the Maritimes Mining Corporation, Limited.'

Canad. Mining and Metallurgical Bull., 1959, vol. 52, Mar., pp. 150–69.

This survey of the procedures and equipment used in mining, milling and concentrating copper ores at Tilt Cove, Newfoundland includes the following brief reference to mill liners (p. 160) which, like that given in the following abstract, is of interest in connexion with the subject matter of the paper abstracted above:

'Liners in both ball mills are of the off-set square-wave pattern, cast in 'Ni-Hard'*, and those in the re-grind mills are of the Hendry off-set wave type, also made in 'Ni-Hard'. None of these shows much wear after 18 months' service.'

D. C. SHELTON: 'Santa Barbara Mill, Chihuahua, Mexico.'

Bull. Inst. Mining and Metallurgy, 1959, Feb., pp. 177–92; disc., *ibid.*, 1959, May, pp. 385–92.

The paper describes the various crushing plants serving the central mill at the Santa Barbara Mine and gives a detailed account of the concentrator flow-sheet.

In the course of the discussion, D. J. OTLEY (p. 387), commenting on data on rod- and ball-mill liners contained in the paper, gave two examples illustrating the importance of shell-liner design and composition. In one plant in Peru handling hard pyritic copper ore, a change from Lorain-type manganese-steel shell liners to a modified continuous-wave type manufactured from chromium-molybdenum steel increased the life of the liners from 200 to 250 days. In the second plant 'Ni-Hard' liners, again of modified continuous-wave design, were substituted for manganese-steel Lorain liners in a mill grinding a softer lead-zinc sulphide ore. Use of the 'Ni-Hard' liners increased liner life from 250 days to 550 days, and the tonnage of ore ground per set was raised from 126,000 to 330,000, representing a reduction in liner costs from 3 cents to 1·3 cents per ton of ore ground.

*Nickel 3·3-4·8, chromium 1·2-1·7, per cent.

Applications of S.G. Iron in Steelworks

A. B. EVEREST: 'S.G. Iron in Steelworks Plant.'
MOND NICKEL CO., LTD., *Publn.* 1659*;
published 1959; 23 pp.

The publication comprises a review of the applications which S.G. iron has found in modern steelworks. Introductory comments on the characteristics of the material are based on a table showing mechanical properties typical of heat-treated S.G. iron (containing about 1 per cent. nickel), acicular S.G. iron (containing about 3 per cent. nickel and 1 per cent. molybdenum) and austenitic S.G. iron (containing 22 per cent. nickel).

Steelworks engineers have been quick to take advantage of the excellent combination of properties (castability, strength and resistance to impact, wear and oxidation) offered by the various grades of S.G. iron. These materials have, for example, been used in many applications to replace grey cast iron, with either reduction in weight or improved service life, and can, especially where improved wear-resistance is desired, often be employed with advantage in parts previously made from steel. In applications requiring heat-resistance the performance of S.G. iron is greatly superior to that of comparable materials previously available.

The author's review of S.G. iron applications covers equipment used in the main stages of steel production, starting with that used in the preparation of coke and the reduction of iron ore in the blast furnace and ending with that employed in the production of semi-finished forms in the rolling mills. Photographs are given of many of the components to which reference is made.

Nickel-containing Cast Iron in Butane-Isomerization Units

See abstract on p. 237.

CONSTRUCTIONAL STEELS

Ultra-High-Strength Steels: Classification and Evaluation

W. B. F. MACKAY: 'Ultra-High-Strength Steels.'
Canad. Aero Jnl., 1959, vol. 5, Jan., pp. 3-12.

This paper is a critical summary of the types of steel now available for applications requiring unusually high strength combined with certain other physical and mechanical properties. For the purpose of the review the term 'ultra-high-strength steels' is defined as 'those high-cleanliness aircraft steels, stainless or otherwise, which possess ultimate tensile strengths varying from 200,000 to 300,000 p.s.i. (90 to 124 t.s.i.; 140 to 210 kg./mm.^{2}), have widely differing load-carrying ability over the temperature range $-85°$ to $+$ 1000°F. ($-65°$ to $+540°$C.), and whose toughness and ductility are usually borderline, according to presently accepted standards'. It is pointed out that the basic problem is not so much one of strength, but rather of utilizing a fraction of the strength now available and combining it with various other desirable characteristics, so that the steel may be fabricated and enter service with properties acceptable to the aircraft designer.

From this standpoint, the author reviews three classes of steel which come into consideration as meeting the requirements:

(1) *Low-Alloy Constructional Steels*

Using low-alloy nickel-chromium-molybdenum steel (of the A.I.S.I. 4340 type) as a base, modifications in composition and treatment have been developed: these are reviewed by the author, and the advantages and limitations of this class of material are outlined. A table shows nominal compositions of fifteen (U.S.) steels which fall into this category.

(2) *Stainless Steels*

Steels of the 'marginal' austenitic type, e.g., 17-7 chromium-nickel, martensitic high-chromium steels, and the precipitation-hardening stainless steels are discussed, with a table giving compositions typical of steels of the respective grades.

(3) *Hot-Work Tool Steels*

The compositions of eleven American brands of tool steel are listed, and the interest of these steels to the aircraft industry (particularly in relation to retention of strength at elevated temperatures) is indicated. Other advantages are also mentioned, and limitations inherent in such steels are listed.

The second section of the paper briefly outlines the problems which face the steelmaker in producing steels which will meet the requirement for ultra-high strength combined with adequate ductility and other essential characteristics. In this connexion reference is made to the necessity for a high standard of cleanliness, to the value of vacuum melting, and to the avoidance of tramp elements. With regard to tests which should be specified to ensure the properties required in the ultra-high-strength steels, it is suggested that the standard tensile test should be replaced by a type of bend test, and the opinion is expressed that in development of these steels some re-evaluation of ductility requirements will have to be made. Ideas with regard to determination of toughness also call for revision, since the notched-bar impact test fails to give significant results on materials of ultra-high hardness and none of the other test methods used in this connexion give results fully representative or acceptable.

Finally, the author considers future developments, in the light of the properties available in the respective groups of steel discussed. The following opinions were expressed, and amplified in discussion:

'Although the (low-alloy) constructional steels are capable of achieving over 300,000 p.s.i. (124 t.s.i.; 210 kg./mm.^{2}) tensile with very low alloy content, their lack of corrosion-resistance and inability to retain their strength even at moderate temperatures

* *We shall be pleased to supply a free copy of this publication.*

limits their potential for further development. Where good ductility and low-temperature impact-resistance are of prime importance, certain of these steels, such as the carbon 0·30, nickel 4·10, chromium 1·24, molybdenum 0·25 type, may warrant further study.

'The most promising ultra-high-strength steels for the immediate future, at moderately elevated temperatures, appear to be the precipitation-hardening, semi-austenitic stainless steels and the super-hot work, semi-high-speed tool steels. The semi-austenitic stainless types have a distinct advantage in thin sections for external applications: on the other hand, the super-hot-work semi-high-speed types are unequalled for load-carrying ability at temperature, and are most suited to thicker sections where some protection against corrosion may be afforded.

'Future development of ultra-high-strength steels will depend largely on obtaining a better understanding of the rôle being played by individual alloying additions and their inter-relations with regard to strength and retardation of softening.'

High-Strength Steels for Aeronautical Applications: Symposium

AMER. SOC. METALS: 'High-Strength Steels for Aircraft.' *A compilation of papers presented at the First Southwestern Metal Congress*, held at Dallas, May 1958. Published by the Society, 1958; 81 pp.

Efforts to develop materials possessing the high strength-to-weight ratios required to meet the demands of the aircraft industry have involved extensive investigation of low-alloy steels heat-treated to strengths in the range 200,000-300,000 p.s.i. (90-133 t.s.i.; 140-210 kg./mm.²). The papers contained in the publication (*see* abstracts below) are concerned with the heat-treatment, properties, processing and applications of such steels. Much of the information given relates to steels of A.I.S.I. 4340 grade (carbon 0·38-0·43, manganese 0·6-0·8, nickel 1·65-2·0, chromium 0·7-0·9, molybdenum 0·2-0·3, per cent.), and modified steels developed from that basis composition.

J. C. HAMAKER: '5 per cent. Chromium Ultra-High-Strength Steel', pp. 1-15.

The author presents data illustrating the properties of 5 per cent. chromium steel, discusses fabrication procedures and applications, outlines the relationship between heat-treatment and the properties obtained, and indicates the future potential of the steel.

J. K. DIETZ: 'Steel Castings in Airframes', pp. 17-20.

The paper is in two parts. In the introductory section the author points out the benefits (in terms of weight saving, flexibility of design, and, in certain cases, superior properties) which may be derived from the use of steel castings in the aircraft industry. The main section is concerned with an analysis of the factors which have deterred designers from specifying cast components.

The following problems are discussed and methods are suggested by which such difficulties may be avoided: low or varying tensile properties in castings, achievement of close dimensional tolerances, defects in critical areas, late delivery of castings from the foundry.

C. E. MOELLER: 'The Use of Steel Forgings at High Strength Levels', pp. 21-9.

The author is associated with the Menasco Manufacturing Company, which is manufacturing landing-gear components (primarily large forgings up to 6 ft. (1·8 m.) in length and up to 1,600 lb. (720 kg.) in weight) from A.I.S.I. 4340 steel heat-treated to strengths in the range 260,000-280,000 p.s.i. (116-125 t.s.i.; 183-197 kg./mm.²). This paper contains notes on imperfections encountered during forging and on the heat-treatments employed to achieve the properties required.

Overheating, flaking, surface-forging defects, excessive amounts of non-metallic inclusions, and inadequate transverse ductility in the forging billet are listed as the principal factors affecting the structural integrity of the forged components. Means of avoiding or minimizing such defects are briefly discussed.

In heat-treating these steels the main problems involved are the possibility of austenite retention during tempering and the risk of '600°F. embrittlement'. Heat-treatments used to prevent these effects are of various types. Precautionary measures against retention of residual austenite include stabilization treatments, refrigeration, and double tempering: the efficacy of these treatments is discussed in relation to test data obtained on 4340 steel. Austempering provides an effective method of avoiding '600°F. embrittlement' and the feasibility of applying this heat-treatment to achieve the strength values required was investigated by determination of the mechanical properties of nickel-chromium-molybdenum steels of A.I.S.I. 4350 and 4340 grades, using various transformation temperatures. The data presented demonstrate that at similar tensile strengths the ductility achieved by austempering is superior to that obtained in quenched-and-tempered specimens.

J. J. RUSS: 'Materials for Hypersonic Weapons', pp. 31-40.

In the field of supersonic missiles and aircraft the design factors with which the structural engineer is mainly concerned are those of strength, weight and space. The principal concern of the material producer, on the other hand, is with the casting and forming facilities available, the workability of the material, the degree to which it is heat-treatable to obtain the required strength properties, and achievement of the necessary heat-resistance. Metallurgical considerations will inevitably limit the degree to which one or more of the design engineer's

requirements can be satisfied. The author correlates available materials with the temperatures for which they are considered suitable:

Room temperature to 350°F. (175°C.)	Aluminium alloys.
350°–600°F. (175°–315°C.)	Titanium alloys and hardenable low-alloy steels.
600°–1000°F. (315°–540°C.)	Tool steels and stainless steels.
1000°–1600°F. (540°–870°C.)	'Superalloys'.
above 1600°F. (870°C.)	Refractory metals and ceramic materials.

In the present paper the author reviews these materials in relation to the three design requirements: space, weight and strength. Density, nominal tensile strength, forgeability index, and maximum service temperatures are tabulated for the individual materials.

In discussion of the high-strength nickel-chromium-molybdenum steels the importance of transverse ductility is emphasized, and reference is made to difficulties encountered in achieving the desired transverse-property requirements throughout a whole heat. In illustration, six graphs are given depicting the transverse characteristics of specimens from 92 heats of steel taken at different locations in different ingots from the same heat.

P. S. KIKELI and F. FARAGO: 'Machining and Fabricating High-Strength Steels', pp. 41–51.

The paper comprises a review of the machining procedures used by the Cleveland Pneumatic Tool Company in the manufacture of landing gears made from two nickel-chromium-molybdenum steels (A.I.S.I. 4340 and S.A.E./A.M.S. 6407) heat-treated, respectively, to strengths in the ranges 200,000–220,000 p.s.i. (90–98 t.s.i.; 140·5–154·5 kg./mm.^{2}), 220,000–240,000 p.s.i. (98–107 t.s.i.; 154·5–169 kg./mm.^{2}), and 260,000–280,000 p.s.i. (116–125 t.s.i.; 183–197 kg./mm.^{2}).

The manufacturing problems involved were fourfold: (1) Components of unusually complex shape had to be machined all over; (2) to meet de-carburization-control requirements, many of the components had to be machined in the heat-treated condition; (3) machining had to be carried out to extremely close dimensional and surface-finish tolerances; (4) the components had to be tempered on a production basis, to hardness never previously used for structural applications.

E. P. KLIER: 'Embrittlement of High-Strength Steels', pp. 53–67.

In his introduction to this paper the author alludes to the misleading use of the term 'embrittlement' as applied to the high-strength structural steels. With the development of design criteria which take into account the restrictions imposed by the fracture characteristics of the steel, it may be expected that the available materials will be used to optimum effect, and scope will be provided for further improvements. The development of such design criteria is, however, contingent on determination of the factors governing crack nucleation and propagation, and, until such information has been established, the suitability of a steel for a specific application can be determined only by tests under conditions simulating those to which it will be exposed in service.

In this context the author discusses crack nucleation and propagation, emphasizing the influence of the size factor, and concludes that 'the overall problem of fracture in high-strength steels consists in establishing the conditions under which critical-sized fracture nuclei are generated and the load conditions under which the nuclei are converted into free-running cracks'. Factors affecting the notch characteristics of notched specimens (in which conditions are most conducive to formation of a free-running crack) are: form of notch, tempering conditions, test temperature, size of specimen, composition of steel, orientation of specimen, hydrogen embrittlement, rate of strain, as-processed section-size, and residual stresses. The present paper is concerned with the effect of these variables on the fracture characteristics of high-strength steels. The data presented in support of the author's observations relate mainly to steels of A.I.S.I. 4340 grade.

The review is in four sections. The first covers discussion of tests (impact-bend and tensile) and the type of notched tensile specimens usually employed to study fracture of steels. The second presents data on the notch strength of the nickel-chromium-molybdenum steel as a function of test temperature, stress concentration, tempering temperature, specimen diameter and tensile strength, and these data are used to throw light on the factors which influence the fracture characteristics of high-strength steels. Embrittlement induced by deposition of hydrogen during electroplating is dealt with in the third section (which is supplemented by data obtained from sustained-load tests on cadmium-plated 4340 steel), and in the last section brief consideration is given to the rôle played by residual stresses in the fracture of high-strength steels.

S. GOODMAN: 'Acceptance Testing of High-Strength Steels', pp. 69–76.

Rigid control must be maintained over composition and processing operations if the required quality is to be achieved in high-strength steels: defects which have adverse effects in steels of normal strength are far more serious in the high-strength grades. In this paper the author outlines the acceptance tests used to ensure such control.

The types of steel which fall within the review, and the importance of control of composition, are illustrated by reference to the nickel-chromium-molybdenum steels 'HS-220', 'Hy-Tuf' and the 4340 and 4330 grades; the higher-strength steels 'Tricent',

'Super Tricent', 'U.S.S. Strux' and 'Hi-C Super-Hy-Tuf'; and the hot-work die steels 'Peerless J' and 'Vascojet 1000'. Acceptance tests associated with control of composition are referred to in general notes on the analytical methods used, and the importance of ensuring that the alloying elements and impurities present are within the stipulated range is emphasized in the light of the deleterious effects which result from a preponderance of any one constituent.

Reference is made to the use of the Jominy hardenability test and to the significance, in this connexion, of establishing the grain-size of the steels. Macro-etching and the use of ultrasonics are considered in relation to testing of soundness, and a note is given on the metallographic test employed to detect overheating during heat-treatment. Testing for decarburization, the importance of tensile testing, and evaluation of high-temperature properties form the remaining subjects of the review.

C. F. LEWIS: 'A Practical Application of the Holloman-Jaffe Parameter to the Tempering of Type 410 Stainless Steel', pp. 77-81.

The author discusses the use of the Holloman-Jaffe tempering parameter, to determine the time/temperature cycle required to achieve a desired hardness in straight-chromium stainless steels.

Hydrogen Embrittlement of Cadmium-Plated High-Strength Steels

A. R. TROIANO: 'Delayed Failure of High-Strength Steels.'

Corrosion, 1959, vol. 15, Apr., pp. 207t-11t; disc. p. 212t.

The author has been associated in recent years with work, carried out at Case Institute of Technology, on delayed failure of cadmium-plated high-strength steels. Previous research had established a definite relationship between the occurrence of embrittlement and the introduction of hydrogen into the steel as a result of pickling and plating. This paper comprises a review of the author's findings to date on the influence of cadmium plating on a low-alloy nickel-chromium-molybdenum steel (A.I.S.I. 4340 grade) heat-treated to high strength levels. Static-load tests on cadmium-plated notched tensile specimens with differing notch radii, and varying in hydrogen content, showed that: (1) notch-tensile strength of the plated steel is below that normal for the unplated steel, and directly reflects the loss of ductility due to hydrogen embrittlement, (2) delayed failure occurs over a wide range of applied stress, (3) rupture time is only slightly dependent upon the applied stress, and (4) there is a maximum critical stress below which failure will not occur (static fatigue limit). The results suggest that delayed failure is governed by a combination of hydrogen concentration and stress: with decreasing hydrogen concentration a higher stress is needed to initiate failure, a concept which is supported by the finding that the static fatigue limit rises as the acuity of the notch is lessened.

The kinetics of crack initiation and propagation were studied by means of an electric-resistance technique. The results indicate the existence of an incubation period for crack initiation, followed by a period of apparently controlled crack growth. It is postulated that diffusion of hydrogen, to provide the necessary concentration for crack initiation in the specimen, is induced by high elastic strain in the region of high triaxiality, and it was found that this effect is reversible: i.e., removal of the applied stress results in a reversal of the direction of diffusion of the hydrogen (see also papers by TROIANO *et al.* abstracted in *Nickel Bulletin*, 1957, vol. 30, No. 7-8, pp. 123-4; *ibid.*, 1958, vol. 31, No. 2, p. 49).

The final section of the paper is concerned with work on factors influencing the effectiveness of baking treatments intended to remove the hydrogen from the steel and so minimize susceptibility to embrittlement. Such treatment has been successful when applied to steels with thin cadmium coatings, but parts carrying heavier coatings remain embrittled even after baking.

Experiments reported demonstrate that the cadmium coating acts as a barrier to the passage of hydrogen, and that a thicker coating forms a more effective barrier than a thin one. Advantage has been taken of this property in the development of a procedure (outlined in the paper) which is claimed to eliminate susceptibility to embrittlement. The treatment involves deposition on the steel of a thin coating of cadmium which is then baked to remove hydrogen. This initial layer provides an effective barrier to the hydrogen discharged in the main plating stage, and a second coating of cadmium may be applied to any thickness without risk of subsequent embrittlement.

Forgeability of Steels: Literature Survey

G. P. CONTRACTOR and W. A. MORGAN: 'Forgeability of Steels: A Critical Survey of the Literature.'

Dept. of Mines and Technical Surveys, Ottawa, Mines Branch Information Circular IC 102, Jan. 17, 1958; 66 pp. Price 25c.

The main aim of the survey, which is based on a *bibliography* of 43 items, was to examine findings reported in the literature on evaluation of the hot-working characteristics of steels. Particular attention was paid to laboratory tests which have been used to determine forgeability, and a large part of the report is taken up by a summary of the influence (as established by the use of such tests) of various alloying elements on forging behaviour.

In reviewing the laboratory tests available, the main emphasis is placed on the limitations and advantages of the 'hot-twist test' (in which the optimum forging temperature is determined as that associated with the maximum number of twists to fracture). Test apparatus is described, and typical test data are discussed. From the information available, it is concluded that the 'hot-twist test' appears to be a

useful method (*a*) of determining the effect of composition and constitution on hot-workability, (*b*) of indicating the best hot-working temperature for steel and the degree of criticality of that temperature, and (*c*) of comparing the hot-workability of a newly developed or unfamiliar steel with that of a steel the hot-twist characteristics of which are already known.

The authors' survey also provided sufficient data from which to draw general conclusions with respect to the effects, on forgeability, of the following alloying or trace elements: carbon, manganese, silicon, sulphur, nickel, chromium, molybdenum, selenium, nitrogen, lead and tin.

Pickling and Acid-Dipping Solutions for Nickel-containing Steels

See abstract on p. 216.

HEAT- AND CORROSION-RESISTING MATERIALS

Investment-Casting Alloys for High-Temperature Service

D. R. WOOD: 'Some Investment-Cast Alloys for High-Temperature Service.'

Foundry Trade Jnl., 1959, vol. 106, June 4, pp. 663-8.

Paper presented at *First Annual Conference, British Investment Casters' Technical Association.*

The paper 'makes no attempt to give an exhaustive review of all the numerous high-temperature casting alloys which have been proposed; the aim is rather to classify the materials according to types, quoting examples of those alloys which have either a long record of useful service or potentialities of particular interest.' Casting alloys commercially available are mainly of iron, cobalt or nickel base, and the information presented in the review relates to alloys representative of these three types: the nickel-chromium (-cobalt) steels 'G-18B', 'WF-176' and 'HR Crown Max', the cobalt-base alloys 'HS-31', 'S-816' and 'G-34', and the nickel-base alloys 'Nimocast 90', 'Nimocast 242', 'Nimocast 258', 'GMR-235' and 'G-39'.

The materials are first reviewed in relation to their high-temperature mechanical properties, and, since a large proportion of the investment castings made in such alloys are used in aircraft-gas-turbine applications requiring resistance to corrosion (particularly by sulphur- or sulphate-containing environments) and to thermal fatigue, the alloys are assessed also from that standpoint. The author's comments on castability are followed by notes on the improvements in properties obtained by vacuum-casting techniques, and in the final section of the paper reference is made to the results of tests (on specimens cut from various 'Nimocast 90' rotors) designed to determine the degree to which test-bar properties correspond to those achieved in actual components. The information given in the review is supplemented throughout by tabular and graphical data.

Precipitation-Hardenable Casting Steels: 'PH-55' Series

N. S. MOTT: 'Four New Stainless Steels.'

Iron Age, 1959, vol. 183, Apr. 16, pp. 118-21.

The article gives details of a series of precipitation-hardenable cast stainless steels developed by Cooper Alloy Corporation. The four steels comprising the series, all of which are basically of 18-8 chromium-nickel-molybdenum type, are designated, respectively, 'PH-55A', 'PH-55B', 'PH-55C' and 'PH-55D'. They are claimed to combine higher hardness and strength with greater resistance to corrosion (especially pitting and stress corrosion) than cast austenitic steels currently available. Although primarily casting steels, two (the A and C grades) have been produced in bar form. Composition limits are as shown in the table below.

Typical mechanical properties are tabulated and the article includes data on corrosion rates of each steel in various concentrations of the following acids and salts, at various temperatures: sulphuric, hydrochloric, nitric, acetic and phosphoric acids, calcium hypochlorite, ferric chloride.

Maximum softness for cold-working and machining is obtained by heating at 2050°F. (1120°C.) for 1 hour + 1 hour for every inch (2·5 cm.) of maximum cross section, followed by water-quenching, and the steels are then hardened by holding at 900°F. (480°C.) for 8 hours and furnace- or air-cooling.

The 'PH-55A' grade is claimed to exhibit high

'PH-55' Steels

Steel	C %	Cr %	Ni %	Si %	Mn %	Cu %	Mo %	Other Elements %
'PH-55A'	0·05 max.	19·5-20·5	8·5-9·5	3-3·75	1 max.	—	3·75-4·25	—
'PH-55B'		19·5-20·5	8·5-9·5	1·25-1·75		3·25-3·75	4·75-5·25	—
'PH-55C'		19·5-20·5	8·5-9·5	3·25-3·75		2·75-3·25	3·75-4·25	—
'PH-55D'		18-21	9-12	3-5		—	3·75-4·25	Nb 0·75-1·25 N_2 0·06-0·15

strength and hardness and excellent resistance to corrosion – erosion-and corrosion-abrasion.

'PH-55B', which is characterized by high strength and greater ductility, but lower hardness, is suitable for corrosion-resisting applications involving stress or shock. The third grade has better corrosion-resistance and higher hardness and strength than 'PH-55A', but is slightly less ductile and resistant to shock. 'PH-55D' is similar to the 'A' grade in composition and corrosion-resistance, but its hardness approaches that of a tool steel.

High-Temperature Materials for Rockets and Missiles

R. G. FRANK and W. F. ZIMMERMANN: 'Materials for Rockets and Missiles.'

Published by *The MacMillan Company*, New York, 1959; 124 pp. Price 31/6; $4·50.

Foreword by R. A. JONES, Chief of Materials Branch, Materials and Equipment Division, Directorate of Development, H.Q. Air Research and Development Command, U.S. Air Force.

The engineering data presented on available high-temperature materials and the review of materials which are expected to become commercially available in the near future are intended to provide the engineer working in the field of rocket and missile technology with a general understanding of ceramics and high-temperature metallurgy. More specifically, the aim is to provide a background of information which will assist in selecting the most suitable material for individual applications. Some idea of the scope of the book may be obtained from the following excerpts from the authors' introduction:

'The chapters of the book do not pretend to present all information available about all high-temperature materials, but rather to give selected information about specially outstanding alloys and ceramic materials of each type. Over-all comparison of materials is made according to chemistry and selected physical properties. . . .

'Throughout the range of temperatures for which data are available, graphs show tensile strength, 0·2 per cent. yield strength, tensile elongation, 10-hr. and 100-hr. stress-rupture strengths, and fatigue strength. Photomicrographs typical of the respective classes of material are shown. The discussion of comparative properties of materials within a given class is designed to afford the reader some insight into the oxidation-resistance, weldability, maximum service temperature, strengthening mechanism, and other characteristics pertinent to the specific class of materials under discussion.

'Properties such as short-time tensile strength and ductility, which have particular significance in rocket and missile applications, are given emphasis. Other important properties considered are: high-temperature oxidation, thermal shock, fatigue, elastic modulus, and certain physical properties, such as thermal conductivity.'

Thermal Conductivity of Aircraft Materials

See abstract on p. 209.

Sigma Phase in Iron-Chromium and Iron-Chromium-Nickel Alloys

C. BELVEDERE: 'Sigma Phase in High-Purity and Commercial Iron-Chromium and Iron-Chromium-Nickel Alloys.'

Metallurgia Italiana, 1959, vol. 14, Apr.; *Atti Notizie Sect.*, pp. 83–97; appendix, pp. 97–9. Disc., pp. 99–100.

A review of the literature, based on a *bibliography* of more than 50 items.

Following a brief historical note on development of studies of this subject, the author reviews available information in sections relating, respectively, to the nature of the sigma phase, conditions for its formation in relation to composition in the types of alloy under review, the effects of sigma on the mechanical properties and corrosion-resistance of the alloys, and formation of sigma in welding. An appendix discusses methods used for identification of sigma phase.

Structure of Precipitation-Hardening Nickel-base High-Temperature Alloys

The papers referred to in the abstracts below form part of a *Symposium on Advances in Electron Metallography* published by the AMERICAN SOCIETY FOR TESTING MATERIALS as *Special Technical Publication No.* 245, 120 pp.

J. R. MIHALISIN and K. G. CARROLL: 'Microstructure of Age-Hardenable Alloys', pp. 68–72.

The paper reports the findings of electron-microscopical examination of the microstructure of nickel-chromium-base age-hardenable alloys subjected to various heat-treatments. Emphasis was placed upon determination of the types and distribution of the age-hardening phases present and their relation to stress-rupture properties and ductility.

Electron micrographs illustrating the paper include typical structures of alloys of compositions similar to those of 'Inconel X' and 'Inco 901'.

W. C. BIGELOW, J. A. AMY, C. L. COREY and J. W. FREEMAN: 'An Electron Metallographic Study of the Precipitation-Hardening Process in Commercial Nickel-base Alloys', pp. 73–87.

The information contained in the paper is closely cognate with that given by BIGELOW and AMY in *Wright Air Development Center Report* No. 58-406, an extended abstract of which was published in *Nickel Bulletin*, 1959, vol. 32, No. 5, pp. 153–5.

W. C. BIGELOW, L. O. BROCKWAY and J. W. FREEMAN: 'The Application of Electron Diffraction and Electron Microscopy in Studies of Minor Phases of Heat-Resistant Alloys', pp. 88–99.

The authors describe the application of a metallographic technique, based on that developed by Heidenreich*, to identification and study of the distribution of minor phases present in four heat-resisting alloys: '16-25-6' (an iron-base alloy containing chromium, nickel and molybdenum), the

* *Jnl. Applied Physics*, 1946, vol. 17, p. 127.

nickel-chromium-base alloy 'Inconel-X', the cobalt-base alloy 'S-816', and the iron-chromium-cobalt-nickel alloy 'N-155 Multimet'.

The technique involves electron-diffraction and electron-microscopical examination of suitably etched surfaces, the procedures used in the preparation of which are outlined. The findings of metallographic study of the '16-25-6' alloy and 'Inconel X' are presented as typical.

Two minor phases ($M_{23}C_6$ and M_6C) were identified in the '16-25-6' alloy, and four (TiN, NbN, $M_{23}C_6$ and γ') in the 'Inconel-X' specimens. In both cases the amount, distribution and identity of the phases were found to vary with the different ageing treatments to which the alloys had been subjected, and some correlation between changes in microstructure and metallurgical properties was possible.

E. J. BROOKS and L. S. BIRKS: 'Electron Probe Analysis of Segregation in 'Inconel' ', pp. 100-5.

The paper gives details of the results obtained from electron-probe microanalysis of precipitates present in the age-hardenable nickel-chromium-base alloy 'Inconel-X'. The submicron grain-boundary precipitates were found to be rich in chromium but poor in other metallic elements, while precipitates several microns in size, which formed in the matrix material or near grain boundaries, were rich in niobium and titanium but poor in chromium. The titanium and niobium content was not uniform from one precipitate to another or within a single precipitate, and some precipitates showed a definite coring effect, with a rich layer of niobium surrounding a titanium core.

Creep of Nickel

See abstract on p. 210.

High-Temperature Properties of 'M-252' Blading Alloy

G. R. FUSNER and D. L. NEWHOUSE: ' 'M-252' Alloy for Heavy-Duty Gas-Turbine Buckets.'

Amer. Soc. Mechanical Engineers, Preprint No. 58-A-191, 1958; 16 pp.

The investigation described was initiated in connexion with the development of a heavy-duty long-life gas turbine designed to operate at a first-stage rotor temperature of 1250°F. (675°C.). Of the high-temperature alloys considered for use as a material of construction for the first-stage rotor, the nickel-chromium-base alloy 'M-252'* appeared to be most suitable. The data already available on the alloy had, however, been established mainly in connexion with its use as a blading material in aeronautical gas-turbine units (i.e., the emphasis was on its performance during operation at elevated temperatures for short periods of time), and were not applicable to operational conditions in industrial gas turbines (long-time service at lower temperatures). The alloy, in various conditions of heat-treatment, was therefore subjected to extensive testing to determine its performance under these different conditions. The results of this test programme are recorded by the authors: the scope of the tests is outlined below.

(1) Tensile tests, on smooth and notched specimens, at temperatures ranging from room temperature to 1350°F. (735°C.).

(2) Stress-rupture tests covering a wide range of temperature and stress.

(3) Creep tests at 1050°, 1250° and 1400°F. (565°, 675° and 760°C.), for times up to 10,000 hours.

(4) Metallographic examination of selected rupture specimens.

(5) Fatigue tests at 1050° and 1250°F. (565° and 675°C.).

(6) Damping tests at 800°, 1050°, 1350° and 1500°F. (425°, 565°, 735° and 815°C.).

(7) Oxidation and oil-ash-corrosion tests.

(8) Rupture tests on specimens machined from turbine blades after 2,046 and 14,539 hours' operational service.

The long-time results confirmed predictions made from short-time tests, and operating experience has given further support to the views held as to the suitability of 'M-252' for use in heavy gas turbines.

*Nickel-chromium-cobalt-molybdenum alloy containing titanium and aluminium.

Influence of Molybdenum on Structure and Properties of Cast Nickel-Chromium Alloys

K. ROESCH and H. ZEUNER: 'The Influence of Molybdenum on the Structure and Mechanical Properties of Cast Nickel-Chromium Heat-Resisting Alloys at High Temperatures.'

Giesserei, 1959, vol. 46, Apr. 23, pp. 202-15.

In contrast to nickel-chromium-base high-temperature alloys which are rendered age-hardenable by small additions of aluminium and titanium (elements readily oxidized during casting), the nickel-chromium-molybdenum heat-resisting alloys, such as those of the 'Hastelloy' series, are easily castable by conventional foundry methods. Due to the urgency of practical requirements, many heat-resisting alloys were originally developed mainly on an empirical basis, but investigations are now proceeding in many countries with the aim of clarifying the structural and other factors which determine the properties obtainable. The experiments described in this paper were carried out on cast nickel-chromium-molybdenum alloys to throw light on the influence of the molybdenum content in this respect.

Three groups of alloys were produced for study. The chromium content was constant, in the region of 20 per cent., and molybdenum ranged from 0 to 16 per cent. The first group, consisting of nickel-chromium alloys with and without molybdenum additions, was used to determine the influence of

molybdenum *per se*. The nickel-chromium-(molybdenum) alloys of the second group varied in carbon content (0·25–0·631 per cent.), and the third group comprised nickel – chromium – molybdenum alloys (containing 0·3 per cent. of carbon) to which about 2·5 per cent. of tungsten had been added.

The structural studies, which are discussed in detail with the aid of photomicrographs, were complementary to investigation of optimum thermal treatments, and involved determination of solubility relationships and identification of precipitates present. In the second phase of the work the properties of the cast alloys were established by short-time tests at room temperature and at high temperatures, and by creep tests at 600°, 700° and 800°C. The results are discussed in the paper in relation to the influence of the molybdenum, carbon and tungsten contents of the specimens. The findings are briefly summarized below.

The influence of molybdenum on the mechanical properties of the alloys is governed primarily by the microstructure. In nickel-base alloys containing 20 per cent. of chromium approximately 16 per cent. of molybdenum is soluble at 1250°C., falling to about 12 per cent. at 750°C. Nickel-chromium-molybdenum alloys containing more than 12 per cent. molybdenum are therefore age-hardenable, with the molybdenum precipitating in the form of a lamellar intermetallic compound. Nickel-chromium and nickel-chromium-molybdenum alloys dissolve approximately 0·01 per cent. of carbon at 700°C., and solubility increases with rise in temperature; at 1300°C. about 0·2 per cent. can be incorporated in the matrix solid solution. Carbon in excess of that amount forms, with chromium, a special carbide which precipitates predominantly at the grain boundaries, but also in some cases within the grains. Solubility tends to decrease with increase in molybdenum content. Carbon dissolved in the solid solution has a strengthening effect, and alloys in which the carbide is precipitated are age-hardenable.

In the nickel-chromium-molybdenum alloys studied, the 2·5 per cent. addition of tungsten was taken into solution with no significant effects on structure or age-hardenability.

The presence of molybdenum considerably improved tensile strength at room temperature and in the range 600°–900°C., and, despite the increase in strength, the alloys in the hardened condition suffered no loss of toughness at molybdenum contents up to the limits of solid solubility at 750°C. (i.e., up to 12 per cent. Mo).

Solid-solution strengthening progressively improved creep properties, and increase in the amount of precipitated phase present was a still more determining factor in this respect. In the straight nickel-chromium alloys strengthening results from addition of up to 12 per cent. molybdenum and to a certain extent from the presence of carbon and of tungsten. The improvements in creep properties (particularly elongation at fracture) which can be achieved in age-hardenable alloys were reflected in the results of tests at 800°C. on nickel-chromium-molybdenum specimens containing about 16 per cent. molybdenum, and in the behaviour of the tungsten and carbon-bearing alloys. The beneficial effects, on creep properties, achieved by addition of tungsten are considered worthy of particular note, though the metallurgical factors underlying them have yet to be clarified. In alloys containing about 12 per cent. molybdenum and 0·3 per cent. carbon, with or without tungsten, formation of intermetallic compounds lowers the toughness to such a degree as to render such materials unsuitable for commercial application.

Recrystallization and Grain Growth of 'Inconel'

D. A. DOUGLAS and J. R. WEIR: 'The Recrystallization and Grain Growth of 'Inconel'.'

U.S. Atomic Energy Commission, Oak Ridge Nat. Lab. Report O.R.N.L.-2406, 1959; 29 pp.

Experiments have shown that cold-working may induce recrystallization in alloys operating at high temperatures, with resultant deterioration in creep-resistance and rupture life. Since many components of nuclear reactors are fabricated by pressure-forming methods, an investigation was made of the effects of cold-work, annealing time and initial grain-size, on a commonly-used nickel-chromium-base high-temperature alloy, 'Inconel'. Sheet specimens of the alloy were rolled to obtain reductions ranging from 5 to 80 per cent., and the recrystallization temperature was determined by hardness measurements and metallographic examination. In conjunction with these experiments, an investigation was made of the stable grain size (with which the stability of the carbide particles are interrelated) at annealing temperatures of 1600°, 1700°, 1800° and 1900°F. (870°, 925°, 980° and 1035°C.).

Conclusions

'The results demonstrate the wide temperature range over which recrystallization of 'Inconel' is possible. It appears that a temperature of 1700°F. (926°C.) will obtain recrystallization of all worked structures, regardless of the severity of the mechanical working, but that the resulting final grain-size, at least for short exposures, will depend on the degree of prior cold-work.

'When the material has a coarse grain-size prior to deformation, a somewhat higher temperature is required for recrystallization. Also, the carbides in the grain boundaries of the worked, coarse-grain material remain fixed when recrystallization occurs, so that the new grains do not receive the usual contribution to their creep-resistance from such particles. Thus, it can be assumed that the mechanical properties of such a structure would be inferior to those of material of a similar grain-size in which the carbides were more favourably situated. This mixed structure is still found in some cases after a 2-hour anneal at 1800°F. (982°C.), and therefore is not completely eliminated until the material is treated at 1900°F. (1038°C.).

'Finally, the initial grain-size or the degree of prior cold work to which the material has been subjected appears to make little difference to the grain-size resulting from a 1900°F. (1038°C.) anneal.'

'NIVCO': Cobalt-Nickel-base High-Damping Turbine-Blading Alloys

A. COCHARDT: 'Application of the Magneto-Mechanical Effect to Produce Alloys of High Damping Capacity and Strength.'

Zeitsch. f. Metallkunde, 1959, vol. 50, Apr., pp. 203–6.

The paper gives particulars of investigations which culminated in the development of a cobalt-nickel-base alloy exhibiting high damping capacity and good elevated-temperature properties. The alloy, which contains 35 per cent. nickel together with small amounts of other elements, is intended for use in turbine blades. It has been given the designation 'NIVCO'.

The information presented in the paper has been previously reported by the author in greater detail: *see* papers referred to in *Nickel Bulletin*, 1957, vol. 30, No. 1–2, p. 6; 1959, vol. 32, No. 4, p. 117.

Corrosion of 'Nimonic 80A' Gas-Turbine Blades by Peat Ash

J. A. WADDAMS and J. C. WRIGHT: 'Studies on Dry Corrosion of 'Nimonic 80A'.'

Metallurgia, 1959, vol. 59, Apr., pp. 161–4.

Prior to reporting the results of experimental work, the authors refer to some relevant earlier investigations, drawing particular attention to studies made by SHIRLEY on dry corrosion in peat-fired gas turbines. In those studies preliminary 1,000-hour tests, on two austenitic steels and on 'Nimonic 80A' in contact with peat at 770°C., had shown severe corrosion, associated with sulphur pick-up. Laboratory tests then demonstrated the effects of various salt mixtures in contact with high-temperature-resistant materials, in conditions comparable with those encountered in the blade zone of the peat-fired gas turbine. It was concluded that the major part of the attack was not caused by gaseous corrosion products, but was initiated by alkali sulphates contaminated with chlorides. As little as 1 per cent. of chloride was sufficient to promote severe attack at temperatures of 700°–800°C. (See *Jnl. Iron and Steel Inst.*, 1956, vol. 182, pp. 144–53; *Nickel Bulletin*, 1956, vol. 29, No. 5, pp. 93–4.)

The work now reported was carried out to throw further light on the cause, nature and mechanism of dry corrosion of the same material, 'Nimonic 80A'. All the more important constituents found in peat ash were examined as possible corrosives.

The investigation comprised two phases:

(1) *Crucible tests, in which cylindrical specimens were immersed, at 800°C., in mixtures representative of various combinations of the more importan constituents found in peat ash.*

In tests of up to 24 hours' duration the specimens were exposed to the following media: air, Na_2SO_4, K_2SO_4, $CaSO_4$, $MgSO_4$, NaCl, $Ca_3(PO)_4$, SiO_2, Fe_2O_3, Na_2HPO_4, Na_2SiO_3, and $Na_2SO_4 + SiO_2$. Tests were also made in the presence of the same corrosive media with additions of NaCl, peat, NaCl + peat, SiO_2 or Fe_2O_3. In continued tests lasting up to 250 hours the environment consisted of peat ash adjusted to a composition typical of that deposited during turbine operation (10 per cent. of Na_2SO_4, 5 per cent. of K_2SO_4 and 1·5 per cent. of NaCl). Comparative tests were made with Na_2SO_4 + 1 per cent. NaCl as the corrosive.

(2) *Study of the mechanism of corrosion, using metallographic and X-ray diffraction techniques.*

The results of the investigation show that the most corrosive constituents of the peat ash are the sulphates of sodium and potassium, particularly when associated with chloride and, in the initial stages of the test, with peat. Calcium sulphate, calcium phosphate, sodium phosphate, sodium chloride and sodium silicate were only moderately corrosive. Chloride accelerated dry corrosion in all the media studied. That the presence of peat at the beginning of the test was conducive to attack is believed to be attributable to the fact that it temporarily provides reducing conditions. Relatively inert materials such as silica and ferric oxide were found to have an inhibiting effect on corrosion. A minimum chloride content appeared to be necessary to cause significant acceleration of corrosion by sulphates.

The second series of tests demonstrated that long-time exposure to a combination of sodium chloride, peat and sulphate renders attack virtually certain, a finding which indicates that dry corrosion of 'Nimonic 80A' blades must be anticipated after long exposure at turbine-inlet temperatures of 725°C.

The mechanism advanced in explanation of sulphate/chloride attack on the alloy involves formation, under reducing conditions, of sulphides: first, sodium sulphide and then, by diffusion of sulphur ions into the matrix, chromous sulphide and nickel sulphide. Oxidizing conditions, following the advancing sulphide front, subsequently cause vigorous oxidation of both nickel and chromium.

Internal Oxidation of Nickel-Chromium Alloys

H. R. COPSON and F. S. LANG: 'Some Experiments on Internal Oxidation of Nickel-Chromium Alloys.'

Corrosion, 1959, vol. 15, Apr., pp. 194t–8t.

Under certain conditions (in atmospheres which are oxidizing to chromium and reducing to nickel, and usually, though not exclusively, at temperatures in the range 1500°–1800°F.: 815°–980°C.) nickel-chromium alloys are subject to a type of attack which is characterized by deep internal oxidation of the chromium. The remaining metal is strongly magnetic, the alloy becomes brittle and, when

broken, shows a dark-green fracture, which has given rise to the designation 'green rot'. In the introduction to their report of an experimental study of this type of attack, the authors review the information available in the literature and describe a typical example of internal oxidation in 80-20 nickel-chromium hanger hooks used in a controlled-atmosphere furnace. Over several years more than thirty cases of rapid internal oxidation have been studied in the laboratories of The International Nickel Company, Inc. A résumé is given of the findings with respect to (1) those associated with carburization or sulphidation, and (2) others which occurred in the absence of any apparent contaminating influences.

Internal oxidation of the type discussed is difficult to reproduce under laboratory conditions, but attempts to simulate the environments which cause such attack have been devised: methods used by The International Nickel Company and its associate The Mond Nickel Company are described in this paper.

The report gives results of tests in which nickel-chromium alloys were exposed to the following types of environment: wet hydrogen (marginally oxidizing) and cyclic exposure to wet hydrogen and to carburizing conditions, carburizing gases, air, and dry and wet carbon monoxide.

The tests in wet hydrogen and in carburizing gases were unsatisfactory, but those in air were more successful. In the first series of tests in air alloys containing up to 18 per cent. chromium were exposed at 1900°F. (1035°C.) for four days; in the second series, which involved a larger number of alloys (including some corresponding to the 'Inconel' composition but containing additions of copper, molybdenum, silicon, niobium or titanium), the specimens were exposed for eight days at 1750°F. (953°C.). Data on weight-gain of the alloys are tabulated. Specimens containing less than 9 per cent. chromium formed a thick external oxide under which there was evidence of internal oxidation. Alloys of higher chromium content suffered only negligible sub-surface attack.

In the tests in carbon monoxide, made under conditions devised by The Mond Nickel Company, the specimens used were of the same composition as those used in the second series of tests in air. The samples were exposed in an atmosphere of dry carbon monoxide at 1750°F. (953°C.) for 1, 4, 8 and 16 days. Metallographic examination showed that in some of the nickel-chromium alloys severe carburization and internal oxidation had simultaneously occurred. Additions of 6 per cent. of iron and 2 per cent. of silicon reduced the rate of attack, and a niobium or titanium content of 2 per cent. was found to confer virtual immunity. The effect of saturating the carbon monoxide with 3 per cent. of water vapour was to increase the depth of internal oxidation in the low-chromium alloys.

The significance of the results, as contributing to an understanding of the mechanism of internal oxidation, is briefly discussed.

Oxidation-Resistance of Nickel-containing Materials at Elevated Temperatures

S. FERRÉ: 'Dry Oxidation of Heat-Resisting Steels and Alloys at Temperatures up to 1200°C.'
Rev. Métallurgie, 1959, vol. 56, Apr., pp. 386-94.

Materials representative of the following four classes of heat-resisting alloys and steels were heated in static air, for times ranging from 20 to 100 hours, at temperatures of 800°, 950°, 1100° and 1200°C.:

(1) Chromium-nickel stainless steels of 18-8 type.

(2) Nickel-chromium-base age-hardenable alloys.

(3) Cobalt-base alloys.

(4) Miscellaneous refractory materials (i.e., a 20-20-20-30 nickel-chromium-cobalt-iron alloy and a titanium-carbide/nickel-cobalt-chromium cermet).

The oxidation behaviour of the various materials tested is discussed in terms of the weight-gain/time curves derived for each temperature, and this discussion is supplemented by reference to the results of metallographic examination of specimens after oxidation. The materials are classified in order of their oxidation-resistance at each of the test temperatures (assessed on the basis of gain in weight in 50 hours). At 800°C. an 18-8 type steel exhibited highest oxidation-resistance: at 950° and 1100°C. best results were obtained with, respectively, the 20-20-20-30 Ni-Cr-Co-Fe alloy and a cobalt-base alloy.

Production and Properties of Nickel-Aluminide Sintered Materials

E. FITZER and P. GERASIMOFF: 'Production and Properties of Nickel-Aluminide Sintered Materials.'
Zeitsch. f. Metallkunde, 1959, vol. 50, Apr., pp. 187-96.

Work by MAXWELL and GRALA on the high-temperature characteristics of nickel-aluminium alloys (*N.A.C.A. Tech. Note No.* 3259, Aug. 1954) demonstrated the excellent oxidation-resistance and high-temperature strength of an alloy containing 82·5 per cent. of nickel. Alloys of this composition would consist of the intermetallic compound NiAl (which melts in the region of 1640°C., a temperature considerably in excess of the melting points of its constituent metals) and the lower-melting Ni_3Al phase (which acts as a binding agent). On the assumption that (1) ductility of the alloys would increase with increase in Ni_3Al content, (2) high-temperature strength would rise with increase in the amount of NiAl present, and (3) powder-metallurgical techniques would present the most effective means of developing alloys containing optimum combinations of the two constituents, the authors investigated methods of producing suitable nickel-aluminide powders and studied the high-temperature properties of the sintered materials.

The major portion of the paper is concerned with a detailed description of a production technique by which successful results were obtained. The process is based on the finding that nickel amalgam

can, in liquid mercury, be reacted with aluminium to form very fine mercury-free nickel-aluminide powders, and that, depending on the operating conditions and the nickel content of the amalgam, it is possible to produce powders containing from 17 to 30 wt. per cent. of aluminium and varying in the phases present. (Reference may be made, in this connexion, to a patent covering such a technique, granted to Siemens Planiawerke A.G. für Kohlefabrikate, the Company with which the authors of this paper are associated: *see* abstract in *Nickel Bulletin*, 1959, vol. 32, No. 4, p. 133.)

It was found that powders so produced could, without further treatment, be compacted into bodies which display excellent sintering characteristics. A single sintering treatment in a hydrogen atmosphere, at a temperature as low as 1200°C., produced densities of 95–99 per cent.

The oxidation-resistance of sintered alloys covering a range of nickel contents was determined by exposure in an air stream at temperatures between 900° and 1300°C. High-temperature strength was assessed by bend tests at temperatures up to 820°C. and by some exploratory creep tests. Finally, an investigation was made of the strengthening effects obtainable by annealing the alloys in an oxidizing atmosphere.

The data presented show that, of the alloys tested, those containing from 80 to 84 per cent. nickel exhibit the highest oxidation-resistance and strength properties. Exposure to air at 1300°C. produced a thick oxide surface film within a few hours, but subsequent exposure for several hundred hours resulted in no further gain in weight. The tests concerned with the effects of an oxidizing heat-treatment showed that such treatment improves the bend-strength but lowers plastic deformability. This finding is discussed.

A maximum bend-strength of 80 kg./mm.^{2} was achieved at 500°C. In creep tests involving bend loading at 700°C. the maximum stress producing no permanent set after 100 hours was 12 kg./mm.^{2} and no discernible fracture under bending occurred in the same time period under a stress of 5 kg./mm.^{2} at a temperature of 820°C. Addition of suitable alloying elements is expected to raise the creep limit even further.

Young's Modulus of Nickel-bonded Titanium Carbide

J. B. WACHTMAN and D. G. LAM: 'Young's Modulus of Various Refractory Materials as a Function of Temperature.'

Jnl. Amer. Ceramic Soc., 1959, vol. 42, May 1, pp. 254–60.

It has frequently been observed that the strength of polycrystalline aluminium oxide changes very little with rising temperature in a relatively low-temperature range (ending at about 1000°C.) but falls very rapidly with further rise in temperature. Literature supporting this statement is referred to by the authors, and the nature of the change of behaviour from the one temperature range to the other is discussed. It has been suggested that the rapid decrease in Young's modulus and shear modulus of aluminium oxide at high temperatures is caused by grain-boundary slip, a view with which the authors are in agreement. The purpose of their investigations was to demonstrate the existence of such slip in that material and in other refractories, and to indicate the range of temperature in which slip begins significantly to affect the elastic moduli of the materials, as measured by a dynamic method at frequencies in the kilocycle range.

The experiments described covered determination of Young's modulus as a function of temperature, for the following materials: single-crystal sapphire and ruby; polycrystalline aluminium oxide, magnesium oxide, thorium oxide, mullite, spinel, stabilized zirconium oxide, silicon carbide, and nickel-bonded titanium carbide ('Kennametal'). For the single crystals, Young's modulus was found to decrease linearly with temperature from 100°C.: for the polycrystalline materials (except silicon carbide, stabilized zirconium oxide, and spinel) the modulus decreased approximately linearly with rising temperature until some range characteristic of the individual material was reached: from that position decrease in the modulus was rapid. For the nickel-bonded titanium carbide the critical position was in the region of 900°C.

Heat-Treatment of 'Nimonic' Alloys

W. BETTERIDGE: 'Treatment of 'Nimonic' Alloys for Special Applications.'

HENRY WIGGIN & CO., LTD., *Publn.* 1602*; 10 pp. *Reprint* from *Metal Treatment*, 1959, vol. 26, Feb., pp. 45–52.

See abstract in *Nickel Bulletin*, 1959, vol. 32, No. 4, p. 116.

Post-Fabrication Treatment of High-Temperature Sheet and Tube Materials

R. W. SWINDEMAN and D. A. DOUGLAS: 'Improvement of the High-Temperature Strength Properties of Reactor Materials after Fabrication.'

Jnl. Nuclear Materials, 1959, vol. 1, Apr., pp. 49–57.

In many of the nuclear reactors currently under development extensive use is made of sheet and tube material. The ideal prerequisites for alloys used in such applications are high-temperature strength and workability, but since these requirements are to some extent mutually antagonistic, a compromise has to be made, with the result that usually neither of the relevant properties of the materials fully satisfies the ideal.

The work described in the present paper was carried out at Oak Ridge National Laboratory with the aim of developing methods of post-fabrication treatment which would confer improved high-temperature strength on materials possessing the required workability.

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* *We shall be pleased to supply a free copy of this publication.*

Three possible methods of achieving this aim were explored: (1) by heat-treatment designed to produce optimum grain size and ageing properties, (2) by carburizing, (3) by selection and control of an environment which, if it could be used in service, would have a beneficial effect on the high-temperature properties of the material. Nickel, and the three nickel-base alloys 'Inconel', 'Hastelloy B' and 'INOR-8' (now designated 'Hastelloy N') were selected for study.

It was found that though there appears to be an optimum annealing temperature for a particular combination of operational stress and temperature, maximum strength properties produced by the appropriate heat-treatment cannot be maintained under the fluctuating conditions of stress and temperature which obtain during service.

Creep and tensile tests on 'Inconel' (0·4 per cent. carbon) and 'INOR-8' specimens (containing the very strong carbide-former molybdenum as well as chromium) were carburized at various temperatures and for various times, and after such treatment gave promising results. Creep rates were greatly reduced and rupture life could be trebled or even quadrupled, but with some sacrifice of ductility at rupture.

The influence of environment on high-temperature characteristics was studied by creep tests in nitrogen and in air. Comparative tests in argon and in nitrogen environment showed that nitrogen increases the rupture life and reduces the creep rate of 'Inconel' at 1500°F. (815°C.). In air the creep rate of the alloy was relatively unaffected by comparison with its behaviour in argon, but rupture life was nearly doubled and elongation at rupture was nearly four times as great. Nickel tested at 1500°F. (815°C.) in argon failed at only 1000 hours, whereas in air, on discontinuance of the test after 10,000 hours, no rupture had occurred. The mechanism of the effects observed in the 'atmosphere' tests is discussed, in relation to work by Shahinian and others. (In this connexion see, for example, abstract in *Nickel Bulletin*, 1958, vol. 31, No. 11, p. 296.)

The authors conclude that all three methods studied (thermal treatment, environmental treatment, and alloying additions) may result in improvement of high-temperature properties. The method which appears to be the most controllable and which provides stability over the greatest range of operating conditions is that of alloying by carburization. Substantial engineering benefits can be derived by use of this technique, without altering the other desirable qualities of the alloys.

Apparatus for Thermal-Shock Testing

E. GLENNY, J. E. NORTHWOOD, S. W. K. SHAW and T. A. TAYLOR: 'A Technique for Thermal-Shock and Thermal-Fatigue Testing based on the Use of Fluidized Solids.'

Jnl. Inst. Metals, 1959, vol. 87, May, pp. 294–302.

The apparatus described permits investigation of the behaviour of materials under conditions of transient thermal stress, such as may be encountered in operation of the blading of a gas-turbine engine. The authors discuss the requirements which would have to be met by a thermal-shock test suitable for this purpose and, in this context, review the various methods available for rapid heating and cooling. It is concluded that the most effective laboratory testing technique (suitable both for rapid cooling and rapid heating) consists in immersing the specimen in a bed of powdered refractory substance supported on a permeable plate and fluidized by a stream of air. Full details of equipment developed on this basis are given in the paper. The apparatus is stated to be simple to use and trouble-free in operation: test conditions are uniform and reproducible, and can be accurately controlled. Results reported as typical of those obtained by this test relate to thermal fatigue of 'Nimonic 90' under cycling between 20°C. and 920°C.

Pickling and Acid-Dipping Solutions for Nickel-containing Materials

See abstract on p. 216.

Apparatus for Determination of Corrosion Rates under Hot-Flux Conditions

A. O. FISHER and F. L. WHITNEY: 'Laboratory Methods for Determining Corrosion Rates under Heat-Flux Conditions.'

Corrosion, 1959, vol. 15, May, pp. 257t–61t.

The primary objective of the investigation described was the development of a laboratory technique by which the corrosion rate of a metal surface which is transferring heat may be correlated with the amount of heat flowing and/or the skin temperature. A secondary objective was to demonstrate the inadequacies of conventional immersion tests at present in use as a means of predicting corrosion rates of surfaces transferring heat.

Three heat-flux corrosion-test techniques were evaluated: a resistance-heating test, a tubular heat-flux test (using a quartz heater), and a 'modified disc-heat-flux technique'. Full details, with drawings, are given of the set-up for, and operation of, each method, and the advantages and disadvantages are discussed. The drawbacks of the first two tests were found to outweigh their advantages, and further work culminated in the development of the third test.

The modified disc-heat-flux apparatus consists of a 1-litre flask fitted with a 1-in. (25-mm.) glass pipe outlet, a thermocouple well, an agitator blade and a condenser. The test plate is fastened to the glass pipe and heat is supplied through the agency of a soldering iron, the flat aluminium head of which is clamped to the underside of the specimen. The technique is stated to have the advantages of speed, accuracy, reproducibility and simplicity; it is capable of simulating service conditions and it does not

involve use of high pressures to achieve temperatures in the region of boiling point. The apparatus does not, however, permit calculation of skin temperatures to an accuracy greater than ± 10C.° and is not suitable for studying the effects of velocity.

The value of the technique is illustrated by descriptions of its application to investigation of the corrosion, under heat-flux conditions, of an 18-8-type steel exposed to steam, and to phosphoric-acid, sulphuric-acid and nitric-acid solutions.

Determination of Copper in Austenitic Steels and Magnet Alloys

C. R. ELLIOTT, P. F. PRESTON and J. H. THOMPSON: 'The Determination of Copper in Certain High-Alloy Steels.'

Analyst, 1959, vol. 84, Apr., pp. 237–9.

In the method described separation is based on the extraction of copper dithizonate with carbon tetrachloride, and final determination of copper absorptiometrically, as its blue bis*cyclo*hexanone oxalyldihydrazone complex. The range of copper concentration covered by the method is about 2 to 10 per cent., but this can be extended in either direction by adjusting the sample weight or the aliquot of solution used in the extraction.

The precision of the method is illustrated by a report of results obtained for copper determinations on three British Chemical Standards, one of which was an 18–8 chromium-nickel steel and the others complex alloys of the nickel-aluminium-cobalt-iron type.

Emissivity of Nickel-containing Alloys and Steels

J. C. MORRIS, B. SCHURIN and O. H. OLSON: 'The Total Emissivity of Aircraft Construction Materials.'

Amer. Soc. Mechanical Engineers, Symposium on Thermodynamics and Transport Properties of Gases, Liquids and Solids, pp. 400–4.

Report published by *McGraw-Hill Publishing Co., Ltd.*, London, 1959. Price 97/-.

Aircraft and missiles flying at large Mach numbers are subjected to high temperatures resulting from aerodynamic heating. The reduction of structural temperatures to safe limits is a serious and expensive problem, which can be reduced by employing radiation cooling, and the effectiveness of this method of cooling depends on the emissivity of the radiating surface.

This paper reports measurements of the total normal emissivities of some pure metals and alloys, as a function of temperature, over the range $-320°$ to $+2500°$F. ($-195°$ to $+1370°$C.). Results are presented for pure molybdenum, tantalum, platinum, copper, molybdenum-containing chromium-nickel steel (A.I.S.I. Type 316), 'A.M. 350' (precipitation-hardening chromium-nickel stainless steel), 'Inconel X', and an aluminium alloy.

Specific Heat of Stainless Steel

J. I. LANG: 'Specific Heat of Materials.'

Amer. Soc. Mechanical Engineers, Symposium on Thermodynamics and Transport Properties of Gases, Liquids and Solids, pp. 405–14.

Report published by *McGraw-Hill Publishing Co., Ltd.*, London, 1959. Price 97/-.

The paper presents results of specific-heat measurements over the temperature range 300°–3000°F. (148°–1649°C.). The measurements were made by the drop-calorimeter method, and measurement of heat content was carried out in a modified Parr calorimeter. The paper includes a discussion of the apparatus and of the operational methods. Materials for which data are presented are as follows: molybdenum-containing austenitic chromium-nickel steel, niobium-stabilized chromium-nickel steel, 'Hastelloy R-235', aluminium oxide, niobium, lithium hydride, synthetic sapphire.

Erosion by Cavitation Attack

D. PECKNER: 'Erosion of Materials by Cavitation Attack.'

Corrosion, 1959, vol. 15, May, pp. 269t–74t.

This paper comprises a discussion of the causes and effects of cavitation, methods of testing susceptibility to cavitation damage, and means for minimizing such attack. The review may be conveniently divided into three sections. In the first the author discusses the relationship between cavitation attack and erosion of metals, and outlines some of the causes of cavitation. In the second he examines the various theories which have been advanced to explain the mechanisms involved in cavitation attack, and suggests measures which might be expected to mitigate the effects of such attack (streamlining, good surface finish and use of erosion-resistant materials). The final section, comprising a critical survey of test techniques, includes detail drawings of apparatus used in the various methods.

It is noted that ratings obtained by the magneto-strictive vibratory test are confirmed by service experience: the severity of the test is such that performance in service is likely to be better than that indicated by the results so obtained.

The paper includes data relating to the effect of hardness on accelerated cavitation testing of chromium stainless steels, the effect of sodium-dichromate inhibitors on the resistance of low-alloy grey iron and 'Ni-Resist' (types 1, 2 and 3) to pitting in water, and the relative erosion-resistance, as measured by the vibratory method, of cast high-tensile brasses, 'Monel' (normal, high-silicon, and aluminium-containing grades), cast 18–8 and 18–2 stainless steels, and 'Ni-Resist'. The data reported relate to tests in distilled water, in sea water and, in the case of the cast irons, in water containing chromate inhibitor.

The review is supported by a *bibliography* of 36 items.

Ultra-High-Strength Steels: Classification and Evaluation

See abstract on p. 219.

Sigma Phase: Its Influence on Intergranular Corrosion of Austenitic Steels

D. WARREN: 'The Effect of Sigma Phase *vs.* Chromium Carbides on the Intergranular Corrosion of Type 316 and 316L Stainless Steels. Part I. A Survey of the Literature.'

Corrosion, 1959, vol. 15, Apr., pp. 213t-20t.

Little is known of the effects of sigma phase on the resistance of stainless steels to attack by corrosive media commonly encountered in service. The sparsity of data and the fact that only one of the three standard intergranular-corrosion tests, the boiling 65 per cent. nitric-acid test, is sensitive to the presence of sigma in the steel (and even in this case behaviour depends on form and distribution of the phase), have led several investigators to question whether sigma phase is, in most environments, detrimental to corrosion-resistance. In an attempt to confirm or refute the justification for these doubts, the author undertook an investigation comprising (1) a survey of the literature on intergranular corrosion of austenitic stainless steels, in particular, as affected by the presence of chromium carbides and sigma phase, (2) a laboratory investigation of the relative effects of chromium carbides and sigma phase on the resistance, to intergranular corrosion, of two 18-8-Mo austenitic steels (A.I.S.I. Types 316 and 316L). The findings of the literature survey, which is based on a *bibliography* of 80 items, are presented in this paper.

The survey opens with a historical review of theories advanced in explanation of intergranular corrosion as related to carbide precipitation, test procedures, and methods of minimizing susceptibility to such attack. Data collated from papers reporting actual service failures due to intergranular attack are summarized in a table listing the type of environment, temperature, period of exposure, component, type and condition of stainless steel, and degree of attack. The summary shows that intergranular corrosion has occurred in service involving at least seven common acids: acetic, hydrofluoric, lactic, nitric, phosphoric, sulphuric and sulphurous. Failures of the same type have occurred in warm sea water and in crude oil plus its fractions, and it has also been found that the following environments can cause severe intergranular corrosion of stainless steels: chlorinated solvents acidified with hydrochloric-acid (e.g., starch slurry), and pickle liquors or sauces. Most of the failures illustrated in the table occurred as a result of welding stainless steel containing more than 0·03 per cent. carbon without subsequent annealing, but some were attributable to stress-relief treatment, elevated service temperatures, or inadequate final annealing treatments. Improved fabrication and heat-treatment practice, and the use of the extra low-carbon or stabilized grades of stainless steel for service in the as-welded condition have, during recent years, greatly reduced the occurrence of intergranular corrosion, but failures from this cause are still reported from time to time.

Test solutions which have been used to produce intergranular corrosion under laboratory conditions are listed in two tables: in the first reference is made to twelve solutions used at different times by various investigators; in the second a résumé is given of modified versions of the three most frequently used tests (the boiling 65 per cent. nitric-acid, the acidified-copper-sulphate and the nitric-acid/hydrofluoric-acid tests). Each of the three tests is discussed in relation to the literature concerning its origin, application and limitations. The search confirmed that comparatively little is known about the influence of sigma phase on the corrosion-resistance of stainless steels, but it has been established that this phase can cause accelerated corrosion in boiling 65 per cent. nitric-acid and in hot, concentrated (40–80 per cent.) sulphuric-acid solutions. Apart from this, there is no evidence to indicate that the presence of sigma phase is necessarily damaging to corrosion-resistance.

See also

D. WARREN: 'The Effect of Sigma Phase *vs.* Chromium Carbides on the Intergranular Corrosion of Type 316 and 316L Stainless Steel. Part II.'

Ibid., 1959, vol. 15, May, pp. 221t-32t.

This paper records the results of the second, experimental, phase of the investigation which followed the literature survey referred to in the preceding abstract.

Since Type 316 (18-8-Mo) and 316L (extra-low-carbon 18-8-Mo) stainless steels are subject to both carbide- and sigma-phase formation, the initial problem was to separate the effects of these two phases. This separation was accomplished by using a Type 316 stainless-steel heat for the study of carbide precipitation and several Type 316L heats for the study of sigma-phase formation. The carbon content (0·05 per cent.) of the Type 316 heat made it possible to produce a continuous grain-boundary network of chromium carbides by heat-treatment for 2 hours at 1250°F. (675°C.). The lower carbon content (0·025 per cent. or less) of the Type 316L heats made them relatively free of carbide precipitation after the short-time heat-treatments used and, at the same time, increased their tendency to form sigma phase.

The effect of sigma phase on the corrosion-resistance of Type 316L stainless steel was evaluated for three different forms of this phase: (1) a continuous grain-boundary network, (2) agglomerated as separate discrete particles in the grain boundaries, and (3) partially transformed ferrite in weld metal.

Intergranular corrosion behaviour of the steels was first evaluated by means of standard laboratory tests: (1) boiling 65 per cent. nitric acid, (2) 10 per cent. nitric-3 per cent. hydrofluoric acid, and (3) electrolytic oxalic-acid etching. Next, the intergranular corrosion behaviour of the same heats was studied in acid media for which these steels are generally used, many of which were chosen because they had been reported as having intergranularly

attacked sensitized stainless steel. The acid media thus selected were 20 per cent. acetic, 20 per cent. citric, 10 and 45 per cent. formic, 85 per cent. lactic, 10 per cent. oxalic, 50 and 70 per cent. phosphoric, and 0·5, 10 and 30 per cent. sulphuric. Most of these tests were conducted at temperatures above the boiling point. The progress of corrosion in the test solution was followed by weight-loss measurements, visual + microscopic examination, and progressive photomicrographs of the corroded areas. Finally, the results of the corrosion tests in various acid media were correlated with the data obtained from the standard laboratory tests.

Some of the specimens of each of the three heats of Type 316L steel were tested in the form of tungsten inert-arc welds. Other specimens were subjected to field tests in 30 per cent. nitric-acid/14 per cent. adipic-acid solution, at 110°C. All the corrosion specimens were activated before exposure.

Full particulars of heat-treatment, test procedures and microstructures are given in the paper. The results, which are presented and discussed *in extenso*, are supplemented by numerous photomicrographs. The author's summary of the findings is quoted below.

'1. The presence of a continuous grain-boundary network of chromium carbides caused Type 316 stainless steel to be susceptible to severe intergranular attack and accompanying deterioration, in numerous acid media in addition to nitric acid. Among these were sulphuric, lactic, acetic, oxalic, citric and phosphoric acids.

'2. As far as could be established, sigma phase in Type 316L stainless steel did not cause intergranular deterioration in any of the acids studied other than nitric acid. The presence of a continuous grain-boundary network of sigma phase caused severe intergranular corrosion of that steel in the standard nitric-acid test.

'3. In view of the above finding, the standard nitric-acid test is not a fair measure of the susceptibility of Type 316L stainless steel to intergranular attack in other corrosive environments. Where that steel is to be used for service involving hot nitric acid or nitric-acid mixtures, the standard nitric-acid test can be usefully applied.

'4. The danger of intergranular attack in service resulting from the presence of a carbide network in austenitic stainless steel has again been emphasized. The use of the standard nitric-acid test or other suitable tests to screen materials such as Types 304, 304L and 316 stainless steel for freedom from harmful carbide precipitation is therefore justified.

'5. The results of this investigation emphasize the need for development of an intergranular-corrosion test capable of screening extra-low-carbon 18-8-Mo steel for freedom from harmful carbide precipitation, without being affected by the simultaneous presence of sigma phase. The 10 per cent. nitric-3 per cent. hydrofluoric acid test might be standardized for this purpose.'

Boiling-Nitric-Acid Corrosion Test: Critical Discussion

H. ZITTER: 'Criticism of the Boiling Concentrated-Nitric-Acid Test as Applied to Corrosion-Resisting Steels.'

Werkstoffe u. Korrosion, 1959, vol. 10, May, pp. 311–21.

This 'critique' was written to combat the tendency, stated by the author to be prevalent among European users of stainless steel, to regard the Huey boiling-nitric-acid corrosion test not only as a means of controlling quality in steels of the same grade but also as a criterion for assessment of corrosion characteristics of a steel in acids other than nitric. The data supporting the discussion (which were culled from a survey of the relevant literature) are presented as evidence confirming the view that, far from being a valid gauge of general corrosion-resistance, the Huey test does not give reproducible results even for steels falling within the range of composition laid down for any one grade, since fluctuations in alloy content affect loss-in-weight.

The author insists that the test can be regarded as valid only as a method of determining susceptibility to intergranular corrosion, and here too its efficacy is doubtful, since it does not differentiate between the presence of sigma phase and chromium-carbide precipitates and provides no correlation between time and temperature of annealing and degree of susceptibility to intergranular attack. The oxalic-acid-etch test is considered by the author to offer the most promising means of obtaining such data, and he urges that this test should be used on a qualitative or semi-quantitative basis, not merely as a supplementary confirmation of the (suspect) data obtained by the Huey test.

(Further discussion of the validity of the nitric-acid test is contained in the paper by WARREN; see abstracts on p. 232.)

Intergranular Corrosion of Welded Nickel-Molybdenum-base Alloys

G. N. FLINT: 'The Corrosion-Resistance of Welded Nickel-Molybdenum Alloys.'

Jnl. Inst. Metals, 1959, vol. 87, May, pp. 303–10.

The addition of molybdenum to nickel markedly improves its resistance to corrosion by non-oxidizing acids, and the commercial nickel-molybdenum-iron alloys containing up to 30 per cent. of molybdenum exhibit exceptionally good resistance, even at high-temperatures, to attack by solutions of hydrochloric, sulphuric and phosphoric acids. The alloys are readily welded, but, in some cases of fusion-welded chemical equipment subjected to severely corrosive conditions, failure has occurred by intergranular corrosion of the material adjacent to the weld metal. A post-welding heat-treatment is effective in eliminating susceptibility to such failure, but is practicable only with relatively small components and has the further disadvantage of raising problems of distortion and scaling. The work reported in this paper was carried out to investigate

the cause of this localized attack and to explore means of preventing it other than by heat-treatment.

Preliminary experiments, in which welded sheet specimens of a nickel-molybdenum-iron alloy (molybdenum 29·1, iron 7·0, silicon 0·25, carbon 0·05, per cent.) were subjected to various concentrations of hydrochloric and sulphuric acids, showed that the welding technique used (oxy-acetylene or argon-arc) had no significant effect on resistance to preferential attack. Consideration of similar types of failure suffered by other materials (e.g., intergranular corrosion in the heat-affected zone of welded austenitic steel) indicated the possibility that susceptibility might be associated with the presence of carbide in the microstructure. Metallographic examination of annealed and argon-arc welded material supported this hypothesis: in the annealed condition the microstructure consisted of a banded dispersion of a globular carbide of the M_6C type, approximating to Ni_3Mo_3C, in a face-centred-cubic matrix; in the welded condition the carbide had been re-precipitated from the fused metal, in long stringers, and slight grain-boundary precipitation had also occurred. Experimental confirmation of the association between carbide re-precipitation and intergranular corrosion was obtained from corrosion tests on a series of pure nickel-molybdenum, nickel-molybdenum-iron, nickel-molybdenum-iron-silicon, and nickel-molybdenum-iron-carbon alloys, produced either by vacuum melting or by powder metallurgy, and forged to bar. The ends of the bars were heated to fusion, and corrosion specimens machined from the fused ends were exposed to boiling 10 per cent. hydrochloric acid for 8 or 28 days and afterwards subjected to metallographic examination. The results presented show that with a carbon content below about 0·005 per cent. no intergranular attack occurred; higher carbon resulted in carbide precipitation and susceptibility to intergranular corrosion.

To elucidate further the metallographic changes involved, sheet specimens of a nickel-molybdenum-iron alloy containing 0·03 per cent. carbon, sealed in 'Inconel' packets to prevent oxidation, were soaked in the range 1175°–1325°C. for varying periods, and water-quenched. The microstructures were examined and the nature of the carbides present was determined by X-ray analysis: details of the heat-treatments and their effects on the constitution of the carbide are given. In other experiments, also described, sheet material was heated at 1250°C. for 5 minutes and cooled at varying rates, to determine the effects of such treatment on carbide precipitation. From the results of these experiments the author concludes that 'the susceptibility of welded nickel-molybdenum-iron alloys to intergranular corrosion is due to solution of the M_6C carbide in the regions adjacent to the weld metal and subsequent re-precipitation of carbide (probably as Mo_2C) at the grain boundaries on cooling from welding temperatures. The re-precipitation of carbide causes formation of grain-boundary zones deficient in molybdenum and of lower corrosion-resistance than the matrix.' Rapid cooling from the solution temperature appeared to suppress any microscopically visible grain-boundary precipitation, but did not confer resistance to intergranular attack.

Five methods of eliminating susceptibility to intergranular corrosion were studied by the author:

(1) Lowering the carbon content of the alloy so that carbides do not occur.

(2) Improving the corrosion-resisting properties of the matrix so that the formation of molybdenum-deficient zones at grain boundaries would not be so damaging.

(3) Formation of an alternative, more stable, carbide.

(4) Reducing the difference in solubilities of the M_6C carbide at the upper and lower temperatures involved.

(5) Preventing re-precipitation of the carbide at grain boundaries.

The experiments carried out in this connexion are described in the paper and the efficacy of each method is discussed. The author summarizes his conclusions as follows:

'Susceptibility to intergranular corrosion may be overcome or minimized by modifications of compositions: e.g., reduction of carbon content to very low values, within the solubility limits, or raising the molybdenum and lowering the iron contents so that the production of molybdenum-deficient zones is made less damaging. Susceptibility to intergranular corrosion is lessened also by additions of vanadium and niobium, which appear to act by retarding re-precipitation of carbide.'

See also *Brit. Pat.* 810,089, an abstract of which is given on p. 240.

Pitting Corrosion of Chromium-Nickel Austenitic Steels in Halide-containing Solutions

G. PIER and W. SCHWENK: 'Investigation of Pitting Corrosion of High-Alloy Chromium-Nickel Austenitic and Ferritic Chromium Steels in Aqueous Solutions containing Halides.'

Werkstoffe u. Korrosion, 1959, vol. 10, Feb., pp. 78–81.

Exposure of chromium-nickel or straight-chromium stainless steels to aqueous solutions containing halides in association with oxidizing media usually gives rise to pitting corrosion, resulting from an active/passive effect. The use of the steels in such solutions is therefore governed by their susceptibility to localized attack in the specific media which will be encountered in service. In this paper details are given of methods by which the susceptibility of the stainless steels to such pitting may be predicted on a quantitative basis.

The paper is concerned with three test techniques:

(1) Measurement, under laboratory conditions, of the polarization-resistance/time curves of specimens

tested in 10 per cent. $FeCl_3 + 0{\cdot}5Fe^{-(II)}$ solution through which an alternating current is passed. Data are presented illustrating the correlation of polarization-resistance and susceptibility to pitting corrosion of 18–10 chromium-nickel steels with or without titanium or molybdenum additions. The technique provides a rapid qualitative method of determining susceptibility to pitting.

(2) The 'K_3 [$Fe(CN)_6$] test', which is stated to offer a means of quantitatively assessing the resistance of the steels to pitting in sodium-chloride solutions. The chloride-ion content of the solution is adjusted to that present in the medium to which the steels are to be subjected in service, and about 0·5 per cent. of the K_3 [$Fe(CN)_6$] indicator is added. The specimen is immersed in the solution and as a result of attack by chloride ions small blue spots appear on the surface in 1–10 minutes. These spots are clearly distinguishable, and make possible determination, in a relatively short time, of the susceptibility of the steel to pitting. The data derived from experiments with this test are presented in the form of curves indicating the resistance of chromium and chromium-nickel steels to pitting attack at room temperature, in sodium-chloride solutions containing up to 100 g. Cl^- per litre. Experiments described in connexion with this test indicate that pitting involves an active/passive reaction: metal ions go into solution at the active (anodic) regions, whilst at the passive (cathodic) surface the electrolyte is reduced.

(3) Determination and examination of the current-density/potential curves.

The significance of such curves is outlined by reference to those obtained on 18–10–Ti steels exposed to solutions containing H_2SO_4 and/or NaCl and/or KNO_3, at boiling point or at 20°C. A certain halide concentration (in combination with optimum conditions of temperature, pH, etc.) is necessary to induce formation of active anode regions, and it is shown that in halide-containing solutions pitting corrosion occurs only at a potential greater than about 150 mV.

Kinetics of the Processes Involved in Oxidation of Stainless Steel in Aqueous Systems

M. STERN: 'Evidence for a Logarithmic Oxidation Process for Stainless Steel in Aqueous Systems.'
Jnl. Electrochemical Soc., 1959, vol. 106, May, pp. 376–81.

Previous investigations by the author (*ibid.*, 1957, vol. 104, Oct., p. 559) had shown that when a passive 18–8-type chromium-nickel stainless-steel electrode is immersed in an oxidizing ferrous/ferric aqueous solution its mixed potential gradually approaches the reversible redox potential of the solution. A better understanding of the nature of the system which has now been gained provides a reasonable explanation of this initial potential/time dependence. The kinetics of the processes involved are described in the present paper.

During the initial time interval an oxidation process occurs, the rate of which decreases with time. This process is most likely one of metal oxidation, since the potential range over which it occurs is more active than the estimated reversible oxygen potential for the system. The kinetics of oxidation of stainless steel are similar to those reported for anodic oxidation of metals which form thin amorphous oxides, and it is therefore believed that evidence of growth of a similar type of oxide on stainless steel has been obtained. At constant potential the oxidation process can be closely described in terms of a logarithmic oxidation equation, and the kinetics are consistent with equations describing ion current through thin oxides as a function of the field across the oxide.

Fracture of Steels in Aqueous Hydrogen Sulphide

F. K. NAUMANN and W. CARIUS: 'Fracture of Steels in the Presence of Aqueous Hydrogen Sulphide.'
Archiv f.d. Eisenhüttenwesen, 1959, vol. 30, Apr., pp. 233–8.

The work described in this paper was concerned with determination of time-to-fracture of steels exposed, under stress, to corrosion by aqueous hydrogen sulphide, and of factors governing such behaviour. (A study of reactions occurring, prior to fracture, at the steel/corrosive interface, and in the steel itself, is reported in the paper referred to in the next abstract.)

Eleven steels were selected for investigation: four were unalloyed (but varied in carbon content), five were chromium-(molybdenum) stainless grades, and two were of 18–8 chromium-nickel type (one stabilized with niobium). Prior to testing, the steels were subjected to different heat-treatments or to varying amounts of cold-working: they were therefore exposed to the hydrogen sulphide in a variety of structural conditions. During exposure most of the steels (in the form of bend specimens) were subjected to a range of stresses designed to determine the correlation between the calculated tensile stress and time-to-fracture. The 18–8 steels were, however, tested in the form of U-bend specimens. Other variables with which time-to-fracture was correlated included tensile strength, yield point, elongation and reduction-in-area at fracture, and hardness.

From the data obtained it is concluded that time-to-fracture bears a hyperbolic relation to tensile stress and hardness. For a given hardness, composition and microstructure have no influence on fracture time: when the product of hardness and tensile stress is below a minimum value fracture does not occur. Fracture was preponderantly transcrystalline and the amount of deformation was small, a finding which indicates the significance of deformation characteristics in relation to crack formation. In this context hardness may be regarded as a reflection of ductility and the amount of work required for fracture. Under corresponding mechanical conditions, fracture time for the passive chromium and chromium-nickel stainless steels is a function of their susceptibility to pitting corrosion.

See also

F. K. NAUMANN and W. CARIUS: 'The Significance of Corrosion Reactions for Crack Formation in Steels Exposed to Aqueous Hydrogen Sulphide.' *Ibid.*, 1959, vol. 30, May, pp. 283–92.

The electrochemical reactions involved in the corrosion of the eleven steels tested in the investigation referred to in the preceding abstract were studied by measurement of the electrochemical potential, under equilibrium conditions, during corrosion, and during passage of an electric current. The findings are fully discussed.

Electrodeposition of Metals on Thorium

See abstract on p. 211.

Uranium Refining: Corrosion-Resistance of Nickel-containing Materials of Construction

F. H. MEYER, F. J. PODLIPEC and T. R. KATO: 'Corrosion Problems Associated with Uranium Refining.' *Corrosion*, 1959, vol. 15, Apr., pp. 168t–70t.

The paper outlines the corrosion problems associated with the refining of uranium-ore concentrates at the Cincinnati plant of the National Lead Company of Ohio. The concentrates come from many parts of the world, and vary considerably in chemical composition: some are high in sulphate, others in chloride content.

The refinery process involves five basic steps: (1) Digestion of the concentrate in nitric acid, (2) recovery of the uranium from the digestion slurry by solvent extraction, (3) concentration of aqueous uranyl nitrate, (4) denitration of the fused hydrated uranyl nitrate, to form uranium trioxide, (5) recovery of nitric acid from the primary extraction-column slurry.

In the green-salt plant uranium trioxide from the ore refinery is fed into a reduction reactor containing a screw conveyor and is reduced with hydrogen formed from dissociated ammonia.

The authors' description of the two processes is supplemented by flow sheets illustrating the stages involved, and reference is made to the materials of construction used for the various components and to the changes which have been made, both in the materials employed and in the process systems themselves, in the light of corrosion problems resulting from variations in composition of the ore processed and the operating conditions.

In phases (1), (2), (3) and (4) of the refinery process the various grades of 18-8 chromium-nickel steel used have given satisfactory service.

In the nitric-acid-recovery system the slurry is concentrated in evaporator units to a viscous material and is then spray-calcined to recover additional nitric acid by absorption of NO_2 gases in an absorber system. Here severe corrosion occurred, due to the presence of small quantities of chlorides and fluorides in the vapour stream. The corrosion was attributed rather to attack by fluorides than by chlorides, and addition to the slurry of five parts of Al_2O_3 per part of fluoride complexed the fluoride ion and greatly reduced corrosion. Data illustrating the reduction in corrosion so effected are given for various alloys and steels, including 18–8-type steels, 'Inco 803', 'Hastelloy C', 'Chlorimet 3', 'Durichlor', 'Duriron' and 'Durimet 20'. An extra-low-carbon 18–8 steel (Type 304L), 'Durichlor', and 'Duriron' exhibited excellent corrosion-resistance.

In the green-salt plant 'Inconel' shafts, which corroded due to attack by hydrogen sulphide, were replaced, with satisfactory results, by a niobium-stabilized stainless steel, which was also used for the reactor tubes. Corrosion rates tabulated for 'Inconel' specimens exposed in the hydrofluorination reactor at high temperatures demonstrate the suitability of the alloy for use as a material of construction in that section of the plant.

Corrosion in Hydrofluoric-Acid Alkylation Units

H. H. BENNETT: 'Summary of Questionnaire Replies on Corrosion in HF Alkylation Units.' *Nat. Assoc. Corrosion Engineers, Tech. Committee Report, Publn.* 59-14. *Corrosion*, 1959, vol. 15, May, pp. 237t–40t.

The report is a corporate contribution to investigation of the nature and extent of corrosion problems in hydrofluoric-acid alkylation units in the petroleum industry. The corrosion problems reported in the replies to the questionnaires sent to the industry are summarized in sections concerned with uniform corrosion, pitting and grooving corrosion, weld decay, hydrogen attack and stress-corrosion cracking. The monograph also includes notes on specific cases of corrosion which were reported to have occurred in component parts of contactors, acid settlers and acid-strippers, and in acid-regeneration, isobutane-fractionating, debutanizer, depropanizer, tar and evacuation systems. Where possible, mention is made of the measures taken to mitigate attack.

Attention is specifically directed to the following points:

The use, on lines and valves, of a paint which permits detection of hydrofluoric acid.

The use of 'Monel'-trimmed gate valves, to replace lubricated plug valves, which proved unsatisfactory because of build-up of corrosion products on the plug.

Building up with 'Monel' weld deposits, in replacement of pump wear rings. The deposits were laid down on both impeller and case, and then machined to give 0·018-in. (0·45-mm.) clearance.

The use of 'Monel' in mechanical pump seals and in bellows of Farris-type relief valves.

The use of 'Monel'/'Teflon' spiral-wound gaskets in exchangers.

The satisfactory performance of Nordstrom hyperseal plug valves with body overlay of 'Monel' and plug overlay of 'Stellite No. 6' weld metal.

The risk of stress-corrosion cracking as a result

of mechanical damage to 'Monel' exchanger tubes (e.g., as can occur during installation or removal).

The superiority of 'Duranickel' (precipitation-hardened nickel) bolting in service involving exposure to hydrofluoric-acid-contaminated atmospheres.

Nickel and Nickel Alloys in Butane-Isomerization Units

J. F. MASON and C. M. SCHILLMOLLER: 'Minimum Corrosion for Butane-Isomerization Units.'

N.A.C.E. Tech. Committee Report, Publn. 59-11. *Corrosion*, 1959, vol. 15, Apr., pp. 185t-8t.

Increasing demand for aviation petrol and for motor fuels of progressively higher octane have forced the refiner to make broader use of olefin alkylation with isobutane. In view of the relatively short supply of isobutane there is much interest in processes for converting the more plentiful normal butane to isobutane, for alkylation.

Two processes are available for isomerization of butanes to isobutane: the vapour-phase and the liquid-phase methods. The main difference, as indicated by the names given, is that in the one case a liquid butane, and in the other case a vapour, is passed, after drying and scrubbing, to the reactor or contactor, where the butane is intimately contacted with a catalyst containing aluminium chloride. Since the activity of the catalyst is greatly increased by addition of anhydrous hydrochloric acid, resistance to corrosion by hydrochloric acid becomes a matter of primary importance in selection of materials of construction for the equipment used. This report considers the corrosive conditions encountered in the various stages involved in the two processes, and records some experience in behaviour of materials which have been used in large-scale plant.

Among the data recorded are the following: corrosion rates of nickel and of 'Monel' in hydrochloric acid at 30°C.; corrosion of nickel-molybdenum-iron-(chromium) alloys ('Hastelloy A' and 'B') in hydrochloric acid at room temperature; effect of temperature on corrosion of nickel and of 'Monel' in 5 per cent. hydrochloric acid, and corrosion of 'Ni-Resist Type 1' in unaerated hydrochloric acid, also at room temperature.

Service experience indicates that, irrespective of the process employed, it is important to take every precaution to ensure that the feed is dry and that it contains a minimum of impurities such as sulphur, pentanes and olefins. In the liquid-phase process it is essential that corrosion-resistant alloys be employed in the catalyst-handling section. Here 'Hastelloy B' has proved outstanding: such equipment lasts indefinitely if the parts are not stressed. In other sections nickel appears to be the most economical selection. In the most severe application (i.e., the reactors) 5-6 years' life can be expected when using ¼-in. (6-mm.) nickel-clad steel or a nickel lining applied by the 'Heliarc' process, to minimize iron dilution.

Welding of 'Nimonic' Alloys

R. LEVICK and P. A. MORGAN: 'Welding 'Nimonic': Practice in the Manufacture of Gas-Turbine Assemblies.'

Aircraft Production, 1959, vol. 21, July, pp. 251-7.

The information given in the paper relates to the following grades of the nickel-chromium-(cobalt)-base alloys of the 'Nimonic' series: 'Nimonic 75', 'Nimonic 80A', 'Nimonic 90', 'Nimonic 95' and 'Nimonic 100'. The authors review of the practices used in welding these alloys is based on experience gained in the fabrication of gas-turbine assemblies.

An introductory section outlining the circumstances which contributed to the development of the five alloys discussed is followed by brief notes (supplemented by tabular data) on physical properties which are relevant in welding these materials. Since the alloys are age-hardenable, the temperatures involved in welding can considerably affect their properties. This point is emphasized by the authors in a short discussion of the post-welding solution- and ageing-treatments recommended for the respective alloys.

The paper ends with a summary of procedures which have been found optimum for welding the 'Nimonic' alloys by the following techniques: oxy-acetylene welding (applicable only to 'Nimonic 75'), argon-arc welding, metallic-arc welding, resistance welding and flash-butt welding. A note is included on the properties of fusion-welded joints. The limitations and advantages of the various processes are mentioned and reference is made to the alloys and the applications for which each particular welding technique is principally used.

Welding of Hardenable Nickel-Chromium-Molybdenum Stainless Steels

R. H. KALTENHAUSER : 'Welding Properties of Chromium - Nickel - Molybdenum Hardenable Stainless Steels.'

Welding Jnl., 1959, vol. 38, May, pp. 228s-31s.

The various types of precipitation-hardenable stainless steel which have been developed during the past few years have already received considerable attention from fabricators, but in order to achieve optimum properties in the many types of welded assembly used in aircraft and other engineering structures, detailed knowledge is required with regard to the metallurgical structures produced in these materials as a result of welding. In this paper the author reports a study of welding characteristics of two typical precipitation-hardening steels, 'AM-350' and 'AM-355'.

'AM-350' is a two-phase chromium-nickel steel which, in the annealed condition, contains approximately 15 per cent. ferrite, in an austenitic matrix. The composition is so balanced that, by suitable heat-treatment, the austenite may be transformed to martensite. On tempering, precipitation-hardening also occurs, but the major strengthening is effected as a result of the martensitic transformation. 'AM-355' is similar in composition but, in the

annealed condition, contains 5 per cent. or less delta ferrite in the austenitic matrix. Upon hardening, by the same heat-treatments as are used on 'AM-350', slightly higher strength levels may be obtained.*

In addition to the normal effects which have to be considered in welding stainless steels, some particular points require consideration in welding the precipitation-hardening types. These points are discussed by the author, and effects peculiarly applicable to the two steels are illustrated by data on the properties of joints made by various processes, examined in the as-welded or the welded- and post-weld heat-treated conditions. Structures produced by welding are shown, and a report on weld-cracking susceptibility is made, on the basis of results obtained in a cruciform restrained-weld test.

The report shows that the two precipitation-hardened steels have good weldability, and that the techniques found appropriate for austenitic stainless steels are generally applicable to these modified types. Both the steels may be resistance welded, in the annealed or the hardened condition. As compared with the technique normally employed for the conventional austenitic steels, minor adjustments are required in the welding current (or welding cycles), to compensate for difference in electrical resistivity. Tension-shear strengths of hardened-plus-welded material are of the same general level as those of material welded and subsequently hardened. The inert-gas tungsten-arc process, with or without filler metal, has been successfully used on both 'AM-350' and 'AM-355', in thicknesses up to about $\frac{3}{4}$-in. (18-mm.) plate. The inert-gas-shielded consumable-electrode process, using 'AM-355' bare wire, has been employed for plate of heavier section. The absence of easily oxidizable elements from these materials makes them suitable for arc welding: both lime- and titania-coated electrodes have been used to deposit material of the 'AM-355' composition. Plate of 'AM-355' has been successfully joined by the submerged-arc process: fluxes for use in this process are still under investigation, with a view to further improvements.

ANALYSIS

Determination of Nickel in Cobalt and its Salts

See abstract on p. 211.

Spectrophotometric Determination of Cobalt, Nickel and Copper

See abstract on p. 211.

Determination of Copper in Austenitic Steels and Magnet Alloys

See abstract on p. 231.

*Extensive information on these steels is given in papers referred to in Nickel Bulletin, 1959, vol. 32, No. 6, p. 188.

PATENTS

Extraction of Nickel from Mixed Cobalt-Nickel Solutions

Small amounts of nickel contained in solutions of mixed cobalt and nickel salts are extracted by the following steps:

(1) metalloids, e.g., sulphur, selenium, tellurium, antimony, arsenic (used singly or in conjunction with one another) are added to the solution, preferably in the presence of copper and of an element more electronegative than nickel (e.g., iron). This operation is carried out at 50°-100°C. and at pH 5. The velocity of the reaction is influenced by the presence of copper and is affected by the state of sub-division of the metal selected as more electronegative than nickel;

(2) the separated nickel is re-dissolved;

(3) the metalloids are regenerated for further use.

STE. D'ELECTRO-CHIMIE, D'ELECTRO-METALLURGIE ET DES ACIERIES ELECTRIQUES D'UGINE (inventors, F. REYNAUD and A. ROTH). *French Pat.* 1,174,631.

Nickel-containing Fungicides

Copper compounds are used as fungicides to combat such cryptogamic diseases as beet and potato mildew, but the amount of compound needed to achieve satisfactory results is high (for example, 2·5-5 kg. of copper oxychloride or 1·2-2·4 kg. of copper oxide for a single treatment of a one-hectare field of potatoes). According to the claims of the patent, it has now been found that the fungicidal effect of copper compounds is greatly increased by addition of small amounts of compounds of nickel, chromium or manganese. The new parasiticides not only considerably reduce the amount of copper compounds needed but also, even if used in excess, cause no damage to the leaves of the plant.

Three of the four examples given relate to a parasiticide of the following composition: copper oxide 30, nickel sulphide 3, polyvinyl-acetate dispersion 25, stabilizers 0·5, water 41·5, per cent. Aqueous suspensions containing 0·2 and 0·25 per cent. of this product were successfully used to prevent, respectively, apple speckling and beet mildew.

FAHLBERG-LIST G.m.b.H. *French Pat.* 1,177,660.

Nickel-Sulphide/Amorphous-Alumina Hydrogenation Catalyst

A nickel-sulphide/amorphous-alumina catalyst, suitable for use in the vapour-phase hydrogenation of nitrobenzene to aniline, is produced from a hydrated nickel aluminate by a conversion process involving heating at a temperature not exceeding 800°C. and sulphiding. The hydrated nickel aluminate is obtained by heating a mixture of precipitated insoluble compounds (comprising hydroxides and/or carbonates of nickel and aluminium) in water for the requisite time. Preferably the catalysts are produced by heating (at 90°-100°C. and in the presence

of water) a co-precipitate of hydroxides and/or carbonates of nickel and aluminium formed by reacting ammonium carbonate with an aqueous solution of water-soluble nickel and aluminium salts. The amorphous alumina in the catalyst functions not only as a carrier, but also as a promoter for the nickel sulphide.

L. O. WINSTROM, assignor to ALLIED CHEMICAL CORPN. *U.S. Pat.* 2,875,158.
(Divided out of *U.S. Pat.* 2,716,135.)

Nickel-Calcium-Phosphate Catalyst in Butene Dehydrogenation

Butene is converted to butadiene by contact (at 1000°–1300°F.: 540°–705°C.) with superheated steam and use of a nickel-calcium-phosphate dehydrogenation catalyst. The spent catalyst is regenerated with steam and excess air and the regenerator effluent is deoxidized by burning fuel in its presence: the oxygen-free steam so produced is then available for use in the dehydrogenation process. Among the advantages of the process are that it enables the reactor and regenerator to be switched from a reaction to a regeneration operation at intervals determined by the life of the catalyst (and so ensures uninterrupted production of butadiene), that fresh-steam requirements are substantially reduced, and that more steam is available for efficient regeneration of the catalyst.

ESSO RESEARCH AND ENGINEERING CO. *Brit. Pat.* 811,209.

Electrodeposition of Duplex Nickel Coatings

Duplex nickel coatings comprising an undercoating of semi-bright nickel on which is deposited a layer of bright nickel are believed to offer improved properties *vis-à-vis* those of a single nickel coating of the same thickness. The production of such coatings has entailed the use of two plating solutions operated under different conditions, one for deposition of each layer. The present invention provides a method of plating whereby duplex coatings of high brilliancy, low stress and good ductility and corrosion-resistance are deposited from the same aqueous nickel-plating solution. The effects of brightening agents are diffusion-controlled, and advantage is taken of this fact to obtain first, in the unagitated solution, a nickel deposit of columnar fibrous microstructure, and then, by vigorous agitation of the electrolyte, a second deposit of lamellar microstructure. The preferred brightening agents are 2-butyne-1,4-diol or a water-soluble sulpho-oxygen compound and a water-soluble acetylenic alcohol.

O. KARDOS and R. P. NEUMANN, assignors to HANSON-VAN WINKLE-MUNNING CO. *U.S. Pat.* 2,879,211.

Electroless Nickel-Plating of Copper-Sheathed Electric Cables

The invention relates to copper- or copper-alloy-sheathed electric cables designed to withstand service temperatures higher than 250°C., and, more particularly, to mineral-insulated cables with copper conductors and sheaths intended for use in aircraft engines under conditions involving exposure in air to temperatures of the order of 250°–400°C. At such temperatures an oxide layer forms on the surfaces of the copper or copper alloys and rapidly flakes off. According to the claims of the patent, flaking is prevented by coating the sheath with an adherent layer of nickel/nickel phosphide (the phosphorus content of the layer being at least 3 wt. per cent.), deposited from a hot aqueous solution containing a nickel salt and a hypophosphite. Preferred alkaline and acid solutions are given and plating procedures are outlined.

BRITISH INSULATED CALLENDER'S CABLES, LTD. (inventors, E. H. REYNOLDS and W. A. WALKER). *Brit. Pat.* 813,993.

Nickel-containing Bearing Material

An improved bearing material is produced by infiltrating a hard sintered matrix (consisting of nickel and a boride of manganese, chromium, molybdenum or tungsten) with silver. The matrix is infiltrated to achieve a density about 100 per cent. of the theoretical value, and the finished material is of the following composition: nickel 45–82, silver 15–35, per cent., balance boride. A preferred composition contains nickel 63, silver 30, chromium boride 7, per cent.

F. C. WAGNER, assignor to HORIZONS, INC. *U.S. Pat.* 2,875,510.

Nickel-Chromium-Cobalt Creep-Resisting Casting Alloys

The stress-rupture properties, at 980°C., of nickel-chromium-cobalt casting alloys rendered age-hardenable by aluminium and titanium additions are improved if the titanium+aluminium content, and the ratio of titanium to aluminium, lie within certain limits. The alloys developed as a result of this finding are stated to combine a useful stress-rupture life at 980°C. with good tensile strength and ductility at room temperature.

Limits of composition of alloys covered by the patent are: chromium 7·5–15, cobalt 5–40, titanium +aluminium 7–9 (ratio of titanium to aluminium 0·6–1·4), carbon 0·05–0·5, molybdenum 0–15, silicon 0–0·8, manganese 0–1, iron 0–10, zirconium 0–0·2, per cent., balance nickel. The alloys may be modified by additions of up to 5 per cent. of tungsten and up to 3 per cent. of niobium and/or tantalum, and a preferred composition includes 0·005–0·1 per cent. of boron. The alloys are intended particularly for use in turbine blades. (Reference is made to earlier kindred patents covering alloys for use in other ranges of temperature.)

MOND NICKEL CO., LTD. (inventors, D. R. WOOD and J. F. GREGG). *Brit. Pat.* 814,029.

Boron-containing Nickel-Chromium-Cobalt Creep-Resisting Alloys produced by Powder Metallurgy

The creep-resisting characteristics of nickel-chromium-cobalt-base alloys produced by conventional methods are known to be improved by addition of up to 0·01 per cent. of boron. In similar alloys produced by powder-metallurgy techniques addition of larger amounts of boron has been found to have a beneficial effect on creep properties, in particular, on elongation at fracture and rupture life. The alloys covered by the patent are based on this finding.

The sintered alloys claimed fall within the following limits of composition: chromium 4–30, cobalt 0–55, iron 0–40, molybdenum 0–20, titanium 0·5–8, aluminium 0·3–8, tungsten 0–5, niobium and/or tantalum 0–5, boron 0·01–0·8, carbon 0·1–0·5, zirconium 0–0·5, per cent., balance (at least 30 per cent.) nickel. A preferred composition comprises: chromium 15–25, cobalt 15–25, titanium 1·8–4, aluminium 0·8–2·5, iron 0·5 max., boron 0·1–0·5, carbon 0·02–0·2, per cent., balance nickel.

The manufacture of such alloys is described and data are presented illustrating the improvements in creep properties achieved.

MOND NICKEL CO., LTD. (inventor, D. K. WORN).
Brit. Pat. 813,948.

Nickel-Chromium-Iron Alloys Resistant to Carburizing and Other 'Special' Atmospheres

Alloys suitable for applications involving long-time exposure to carburizing atmospheres at high temperatures fall within the following limits of composition: nickel 40–50, chromium 27·5–33, carbon 0–0·5, silicon 0–1·5, manganese 0–2, nitrogen 0–0·2, per cent., balance iron.

The alloys are resistant also to 'green-rot' and to attack by sulphur, and, in comparison with alloys of higher nickel content, show less tendency to catalytic behaviour when in contact with hot hydrocarbons. Suitable applications are carburizing boxes, cyanide pots and salt-bath fixtures, radiant tubes used under carburizing conditions, and furnace tubing used in the production of ethylene from ethane and propane.

MOND NICKEL CO., LTD. (inventor, E. N. SKINNER).
Brit. Pat. 810,366.

Production of Stainless-Steel and Nickel-Alloy Powders

Metal powders are manufactured by a process which comprises subjecting a flowing stream of the molten metal to the action of a jet of water in an atmosphere of a non-oxidizing gas whilst, to prevent spray-back, continuously introducing into the jet of water a volume of non-oxidizing gas sufficient to satisfy its tendency to inspirit gas. Nitrogen is the preferred non-oxidizing gas.

Application of the process to production of metal powders of the following materials is specifically claimed: '18-8' chromium-nickel stainless steel, 80–20 nickel-chromium alloy, ferro-chromium, and a 70–30-type nickel-copper alloy.

F. W. BERK AND CO., LTD. (inventor, F. B. WEBB).
Brit. Pat. 812,342.

Nickel-Molybdenum-Iron Alloys Resistant to Intergranular Corrosion

The invention is based on the finding that susceptibility to intergranular corrosion induced, as a result of welding, in nickel-molybdenum-iron alloys is avoided, without deleterious effects on hot-working characteristics, if the alloys contain from 1·2–2·3 per cent. of vanadium.

The alloys claimed fall within the following limits of composition: molybdenum 20–35, iron 15 max., vanadium 1·2–2·3, cobalt 0–5, chromium 0–5, silicon 0–1, manganese 0–3, aluminium 0–2, carbon 0·25 max., per cent., remainder nickel. Part of the molybdenum may be replaced by up to 10 per cent. of tungsten. The expression

$$2(\%\text{Mo}-20)+5(\%\text{V}-1\cdot2)+10(\%\text{Si}-0\cdot2)+\%\text{Cr}$$

should not exceed 30. Before welding, the alloys may advantageously be subjected to a carbide-coarsening heat-treatment which reduces the tendency of the molybdenum carbide to go into solution during welding.

Components fabricated from the alloys by welding, and used, in the as-welded condition, in contact with such corrosive media as hydrochloric acid, are also claimed.

MOND NICKEL CO., LTD. (inventor, G. N. FLINT).
Brit. Pat. 810,089.

Low-Melting Nickel-Iron Brazing Alloys

The brazing alloys claimed (nickel 51–85, chromium 10 max., manganese 10 max., boron 1–5, silicon 0·25–5, and phosphorus 0–3, per cent.), have an iron content (within the range 6–40 wt. per cent.) sufficient to lower the melting point to the region of 1700°–1850°F. (925°–1110°C.), thus facilitating application of the brazing medium to base metals. A preferred composition, given as nickel 65, iron 25, boron 3·5, silicon 4·5, phosphorus 1·25, per cent., has a melting point in the range 1700°–1750°F. (925°–955°C.).

A. T. CAPE, assignor to COAST METALS, INC.
U.S. Pat. 2,880,086.

Fusion Welding of Ferritic Steel to Austenitic Steel

Difficulties involved in fusion welding of ferritic to austenitic steels are eliminated by interposing between, and welding to, the two steels a transition piece having a continuously varying composition such that its coefficient of expansion increases progressively from $14\cdot10^{-6}$ at one end to $18\cdot10^{-6}$ at the other (i.e., from the coefficient of the ferritic steel to that of the austenitic). The insert is produced by powder metallurgy, using powders mixed in the proportions required to obtain a progressive variation in coefficient of expansion. It may be conical in shape with a cylindrical bore, or cylindrical, and its thickness is such as to ensure uniform strength at high temperatures in all its sections. In a joint obtained by means of the invention, the weld and the transition piece at the end nearest the ferritic

steel should contain a high percentage of nickel (e.g., 50 per cent.): that used at the austenitic end is 'similar in composition to the austenitic 18–8 steel and of the welding metal used on that side'.

In the preamble to the patent, methods of manufacturing the transition piece, and powder alloys suitable for use in this respect, are discussed.

BUREAU D'ETUDES INDUSTRIELLES FERNAND COURTOY (inventor, F. ZIMMER). *Brit. Pat.* 813,154

Corrigendum

Nickel Bulletin, 1959, vol. 32, No. 4, p. 116.

The value for the nickel content of 'D–979' given in the article in *Iron Age* and reproduced in the table *Compositions of 'D–979' and 'AF–71' Alloys* should read 45 (instead of 15) per cent. In last column of table on that page, for 'Ni' read 'N'.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.